Dal sito del CERN http://www.cern.ch

ACCELERATORS AT CERN

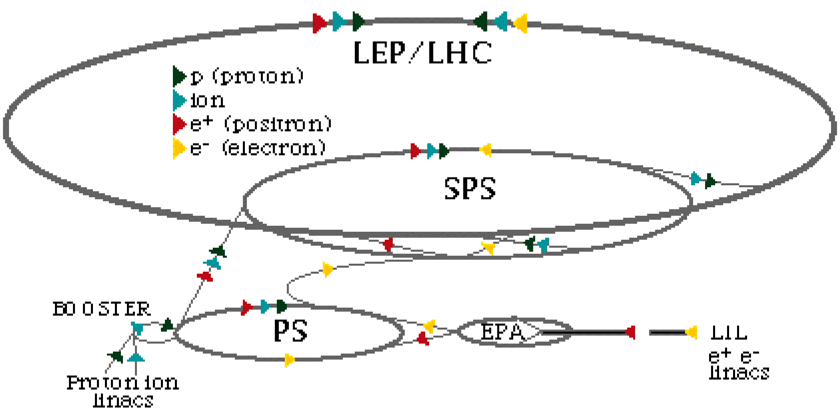
From CERN web site
CERN, Geneva, Switzerland

1. INTRODUCTION

By accelerating particles to very high energies and smashing them into targets, or into each other physicists can unravel the forces acting between them. CERN's accelerators are amongst the world's largest and most complex scientific instruments. Built at the leading edge of technology, these are some of the finest monuments of 20th century science.
Accelerators come in two types, linear and circular, and CERN has both. Accelerators use powerful electric fields to push energy into a beam of particles. Magnetic fields are used to keep the beam tightly focused, and in circular machines to steer the particles around the ring.
Linear machines push energy into the beam all along the accelerator's length. The longer the machine, the higher the final energy.
In circular machines the particles go round and round again, collecting energy with each lap. But the faster the particles are going, the more they try to 'skid' off the ring, just like cars going round a tight curve in the road. CERN's biggest accelerator, the Large Electron Positron collider LEP, is 27 kilometres round, keeping the curves as gentle as possible.
With the largest interlinked accelerator complex in the world CERN is unrivalled in providing beams of high energy particles for physicists to use in their experiments. CERN's accelerators juggle with all kinds of different particles, for all kinds of different experiments.

2. THE CERN ACCELERATOR COMPLEX

CERN's accelerator complex is the most versatile in the world and represents a considerable investment. It includes particle accelerators and colliders, can handle beams of electrons, positrons, protons, antiprotons, and "heavy ions" (the nuclei of atoms, such as oxygen, sulphur, and lead). Each type of particle is produced in a different way, but then passes through a similar succession of acceleration stages, moving from one machine to another. The first steps are usually provided by linear accelerators, followed by larger circular machines. CERN has 10 accelerators altogether, the biggest being the Large Electron Positron collider (LEP) and the Super Proton Synchrotron (SPS).



CERN's first operating accelerator, the Synchro-Cyclotron, was built in 1954, in parallel with the Proton

Synchrotron (PS). The PS is today the backbone of CERN's particle beam factory, feeding other accelerators with different types of particles. The 1970s saw the construction of the SPS, at which Nobel-prize winning work was done in the 1980s. The SPS continues to provide beams for experiments and is also the final link in the chain of accelerators providing beams for the 27 kilometre LEP machine. CERN's next big machine, due to start operating in 2005, is the Large Hadron Collider (LHC). For all these large projects, CERN took a series of measures to preserve the environment.

2.1 The PS complex: the injector for the big accelerators

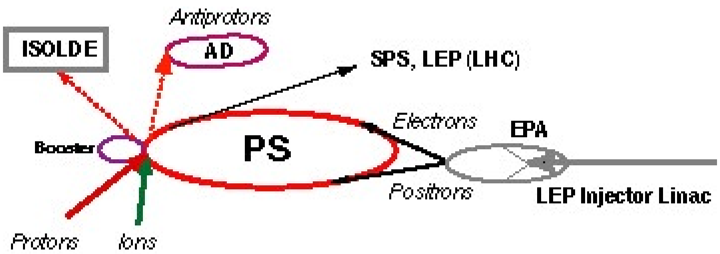
The Proton Synchrotron (PS) is the oldest and most versatile of CERN's accelerators. The PS was commissioned in 1959 and has been running continuously ever since. With a diameter of 200 metres and reaching a final energy of 28 GeV, it was for a while the most powerful accelerator in the world.

The PS has been modified strongly since then, adapting it to the ever increasing complexity of CERN's accelerator system. Today the PS complex can accelerate all stable and electrically charged particles (electrons, protons), their antiparticles (positrons, antiprotons), and different kinds of heavy ions (oxygen, sulfur, or even lead).

These particles are produced in ion sources: protons are obtained from hydrogen gas using a "duoplasmatron", electrons are extracted from metal surfaces in "electron guns", and the electron shells of lead atoms are stripped off in "electron cyclotron resonance (ECR)" sources.

The first stage of acceleration happens in a linear accelerator (Linac), and each type of particle has its own. This is because of their very different masses - a lead ion is about 200 times heavier than a proton, and almost 400,000 times heavier than an electron. The final energies are 500 MeV for electrons, 50 MeV for protons, and 4.2 MeV/nucleon for lead (Pb) ions.

For proton and heavy ion beams then follows a 1.0 GeV "Booster" synchrotron to increase the energy prior to injection into the PS. Electrons are first stored and further accelerated in the "Electron-Positron-Accumulator (EPA)" ring. Anti-electrons (positrons) are produced in collisions of an electron beam with a heavy metal target, and then also stored and accelerated in the EPA.



Then all particle beams pass through the PS machine itself. Each acceleration cycle takes 2.4 seconds, and the PS control systems are so versatile that different particle beams can be dealt with on each successive cycle. The beams are then injected into the bigger rings for further acceleration (SPS, LEP or - in future - LHC). Proton beams from the PS complex are also used for physics experiments (ISOLDE, East Hall) or for the production of antiprotons (Antiproton Decelerator).

2.2 The Super Proton Synchrotron (SPS)

The Super Proton Synchrotron is a circular accelerator, 6 km in circumference, buried underground. It was built originally to accelerate protons - and still does so - but it has since operated as a proton-antiproton collider, a heavy-ion accelerator, and an electron/positron injector for LEP. As a proton-antiproton collider in the 1980s, it provided CERN with one of its greatest moments - the first observations of the W and Z particles, the carriers of the weak force.

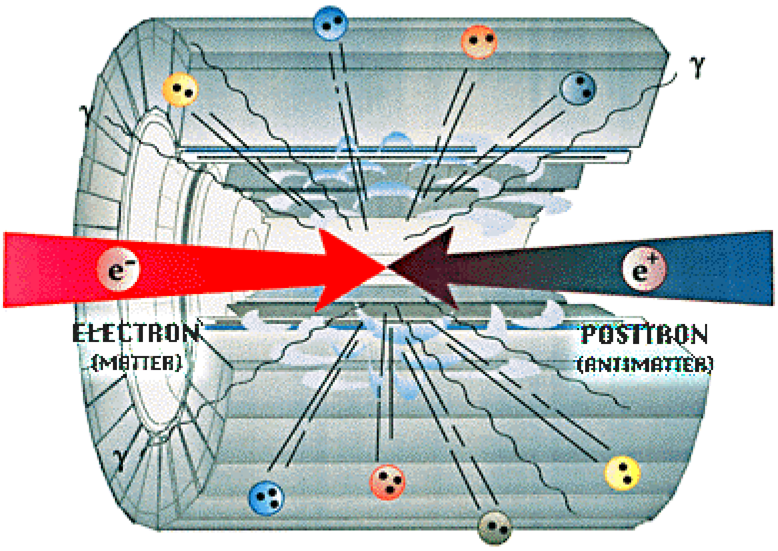
The SPS can also accelerate lead ions to an energy of 170 GeV per nucleon, with 208 nucleons in the lead nucleus. At present, this is the highest energy obtained in the world, and it serves the study of the quark-gluon plasma which may have occured shortly after the big bang.

2.3 The Large Electron Positron Collider (LEP)

The LEP machine at CERN is the largest particle collider in the world. In a ring 27 km in circumference, buried about 100 m underground, bunches of electrons and positrons (antielectrons) race round in opposite directions as they are accelerated to almost the speed of light.

When an electron and a positron come close enough, they disappear in an act of mutual destruction to form a burst of energy. Almost immediately, this energy changes back into particles, just as matter must have formed from energy in the early Universe.

At four symmetric points around the ring, the bunches of particles are focused down to the thickness of a hair and made to collide at the heart of the four LEP experiments. Each bunch contains more than a hundred thousand million particles (10^{11}), but on average only one in about 40 000 collisions between the bunches produces the desired effect - a head-on electron-positron collision. For this reason, the bunches are made to circulate for hours, each bunch travelling round the ring more than 10 000 times a second.



LEP began operation in the summer of 1989 and for six years the collision energy of its electrons and positrons was tuned exactly to the value needed to produce the neutral carrier of the weak force, the Z^0. Since the autumn of 1995, the energy has been increased to almost double its earlier value. In the summer of 1996, LEP ran at the exact value needed to produce pairs of the charged carriers of the weak force, the W^+ and W^- particles. Detection of millions of Z^0s and hundreds of Ws has allowed the LEP experiments to make extremely precise tests of the Standard Model of particles and their interactions.

2.4 The Large Hadron Collider (LHC)

Since the mid-1980s, a new round of discussions has been taking place with the aim of defining various options for the post-LEP era.

There is a general consensus among the world's scientific community that by reaching higher energies we shall probably be able to answer fundamental questions left unanswered by LEP, the most important being the mechanism which gives matter its mass.

In December 1994 CERN's governing body, Council, officially approved the construction of CERN's Large Hadron Collider (LHC) - a technologically challenging superconducting ring, which will be installed in the existing LEP tunnel - to provide proton-proton collisions at energies 10 times greater than any previous machine.

In keeping CERN's cost-effective strategy of building on previous investments, it is designed to share the 27-kilometre LEP tunnel, and be fed by existing particle sources and pre-accelerators. A challenging machine, the LHC will use the most advanced superconducting magnet and accelerator technologies ever employed.

LHC experiments are, of course, being designed to look for theoretically predicted phenomena. However, they must also be prepared, as far as is possible, for surprises. This will require great ingenuity on the part of the physicists and engineers.

Dal sito del CERN http://www.cern.ch

THE LARGE ADRON COLLIDER (LHC) PROJECT

From CERN web site
CERN, Geneva, Switzerland

1. GENERAL INFORMATION

The LHC is an accelerator which brings protons and ions into head-on collisions at higher energies than ever achieved before. This will allow scientists to penetrate still further into the structure of matter and recreate the conditions prevailing in the early universe, just after the "Big Bang".
The LHC will be built astride the Franco-Swiss border west of Geneva, at the foot of the Jura mountains, in front of the Alps.

1.1 The History of the LHC Project

During the first half of this century, achievements in Europe dominated progress in the physics, from the discovery of the electron to the atomic nucleus and its constituents, from special relativity to quantum mechanics. Sadly, the conflicts of the 1930s and 40s interrupted this as many scientists had to leave for calmer shores. The return of peace heralded some decisive changes. By the early 50s, the Americans had understood that further progress needed more sophisticated instruments, and that investment in basic science could drive economic and technological development. While scientists in Europe still relied on simple equipment based on radioactivity and cosmic rays, powerful accelerators were being built in the US. Table-top experiments were being overtaken by projects involving large teams of scientists and engineers.
A few far-sighted physicists, such as Rabi, Amaldi, Auger and de Rougemont, perceived that co-operation was the only way forward for front-line research in Europe. Despite fine intellectual traditions and prestigious universities, no European country could cope alone. The creation of a European Laboratory was recommended at a UNESCO meeting in Florence in 1950, and less than three years later a Convention was signed by 12 countries of the Conseil Européen pour la Recherche Nucléaire. CERN was born, the prototype of a chain of European institutions in space, astronomy and molecular biology, and Europe was poised to regain its illustrious place on the scientific map.
CERN exists primarily to provide European physicists with accelerators that meet research demands at the limits of human knowledge. In the quest for higher interaction energies, the Laboratory has played a leading role in developing colliding beam machines. Notable "firsts" were the Intersecting Storage Rings (ISR) proton-proton collider commissioned in 1971, and the proton-antiproton collider at the Super Proton Synchrotron (SPS), which came on the air in 1981 and produced the massive W and Z particles two years later, confirming the unified theory of electromagnetic and weak forces. The main impetus at present if from the Large Electron-Positron Collider (LEP), where measurements unsurpassed in quantity and quality are testing our best description of sub-atomic Nature, the Standard Model, to a fraction of 1% soon to reach one part in a thousand. By 1996, the LEP energy was doubled to 90 GeV per beam in LEPII, opening up an important new discovery domain. More high precision results are expected in abundance throughout the rest of the decade, which should substantially improve our present understanding. The LEP/LEPII missions will by then be largely completed.
LEP data are so accurate that they are sensitive to phenomena that occur at energies beyond those of the machine itself; rather like delicate measurement of earthquake tremors far from an epicentre. This gives us a "preview" of exciting discoveries that may be made at higher energies, and allow us to calculate the parameters of a machine that can make these discoveries. All evidence indicates that new physics, and answers to some of the most profound questions of our time, lie at energies around 1 TeV (1 TeV = 1,000 GeV).
To look for this new physics, the next research instrument in Europe's particle physics armoury is the LHC. In keeping CERN's cost-effective strategy of building on previous investments, it is designed to share the 27-kilometre LEP tunnel, and be fed by existing particle sources and pre-accelerators. A challenging machine, the LHC will use

the most advanced superconducting magnet and accelerator technologies ever employed. LHC experiments are, of course, being designed to look for theoretically predicted phenomena. However, they must also be prepared, as far as is possible, for surprises. This will require great ingenuity on the part of the physicists and engineers.
The LHC is a remarkably versatile accelerator. It can collide proton beams with energies around 7-on-7 TeV and beam crossing points of unsurpassed brightness, providing the experiments with high interaction rates. It can also collide beams of heavy ions such as lead with a total collision energy in excess of 1,250 TeV, about thirty times higher than at the Relativistic Heavy Ion Collider (RHIC) under construction at the Brookhaven Laboratory in the US. Joint LHC/LEP operation can supply proton-electron collisions with 1.5 TeV energy, some five times higher than presently available at HERA in the DESY laboratory, Germany. The research, technical and educational potential of the LHC and its experiments is enormous.

1.2 LHC – Challenges in Accelerator Physics

High luminosity
In the LHC the energy available in the collisions between the constituents of the protons (the quarks and gluons) will reach the TeV range, that is about 10 times that of LEP and the Fermilab Tevatron. In order to maintain an equally effective physics programme at a higher energy E the luminosity of a collider (a quantity proportional to the number of collisions per second) should increase in proportion to E^2. This is because the De Broglie wavelength associated to a particle decreases like 1/E and hence the *cross section* of the particle decreases like $1/E^2$. Whereas in past and present colliders the luminosity culminates around $L = 10^{32}cm^{-2}\ s^{-1}$, in the LHC it will reach $L = 10^{34}cm^{-2}\ s^{-1}$. This will be achieved by filling each of the two rings with 2835 bunches of 10^{11} particles each. The resulting large beam current (I_b = 0.53 A) is a particular challenge in a machine made of delicate superconducting magnets operating at cryogenic temperatures.

The beam-beam effect limits the bunch density
When two bunches cross in the center of a physics detector only a tiny fraction of the particles collide head-on to produce the wanted events. All the others are deflected by the strong electromagnetic field of the opposing bunch. These deflections, which are stronger for denser bunches, accumulate turn after turn and may eventually lead to particle loss. This *beam-beam effect* was studied in previous colliders, where experience showed that one cannot increase the bunch density beyond a certain *beam-beam limit* to preserve a sufficiently long beam lifetime. In order to reach the desired luminosity the LHC has to operate as close as possible to this limit. Its injectors, the old PS and SPS, are being refurbished to provide exactly the required beam density.

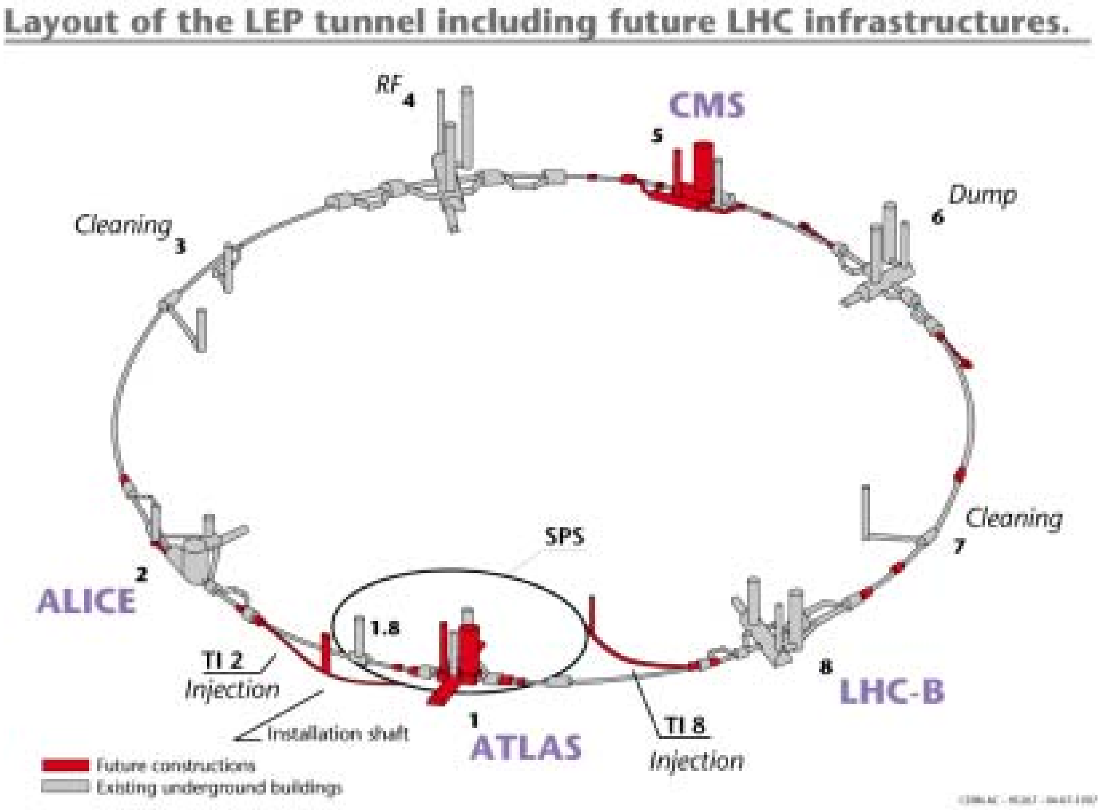
Collective instabilities must be controlled
While travelling down the 27 km long LHC beam pipe at a speed close to the speed of light, each of the 2835 proton bunches leaves behind an electromagnetic *wake-field* which perturbs the succeeding bunches. In this way any initial disturbance in the position or energy of a bunch is transmitted to its companions, and under certain phase conditions their oscillations can be amplified and lead to beam loss. These *collective instabilities* can be severe in the LHC because of the large beam current needed to provide high luminosity. Their effect is minimized by a careful control of the electromagnetic properties of the elements surrounding the beam. For instance the convolutions of the thousands of bellows which are used to allow the machine to contract during cooldown are shielded from the beam by thin fingers equipped with sliding contacts; the inner side of the stainless steel beam pipe is coated with pure copper to reduce its resistance to beam induced wall currents. However these precautions cannot suppress all instabilities, and sophisticated feedback systems as well as non linear lenses are being designed to damp the remaining ones.

Articles have to remain stable for long times
The beams will be stored at high energy for about 10 hours. During this time the particles make four hundred million revolutions around the machine, a truly astronomical number. Meanwhile the amplitude of their natural oscillations around the central orbit should not increase significantly, because this would dilute the beams and degrade luminosity. This is difficult to achieve, since, in addition to the beam-beam interaction already mentioned, tiny spurious non linear components of the guiding and focusing magnetic-fields of the machine can render the motion slightly *chaotic*, so that after a large number of turns the particles may be lost. Studies concerning the *onset of chaos* have become very popular recently in many scientific domains: in particular astronomers now believe that planets in the solar system would show chaotic behaviour if observed for millions of years! The designers of particle colliders take part in this widespread effort, which has direct implications in their field. In the LHC the destabilizing effects of magnetic imperfections is more pronounced at injection energy, because the imperfections are larger owing to persistent current effects in the superconducting cables, and also because the beams occupy a larger fraction of the coil cross section. We must evaluate the *Dynamic Aperture*, the fraction of the coil cross section within which particles remain stable for the required time, and make sure that it exceeds the dimension of the injected beam with a sufficient safety margin. For the time being, no theory can predict with sufficient accuracy the long term behaviour of particles in non linear fields. Instead we use fast computers to track hundreds of particles step by step through the thousands LHC magnets for up to a million turns. Results are used to define tolerances for the quality of the magnets at the design stage and during production.

Beam losses should not quench the magnets
Despite all precautions the beam lifetime will not be infinite, in other words a fraction of the particles will diffuse towards the beam pipe wall and be lost. In this event the particle energy is converted into heat in the surrounding material and this can induce a quench of the superconducting magnets, thus interrupting operation for hours. To avoid this a collimation system will catch the unstable particles before they can reach the beam pipe wall, so as to confine losses in well shielded regions far from any superconducting element. The LHC combines for the first time a large beam current at very high energy with the most sophisticated superconducting technology. As a consequence it needs a much more efficient collimation system than previous machines.

The LHC lattice should be flexible
A modern accelerator or collider is a huge investment which must remain a useful research tool for a long time, and therefore should be adaptable to emerging needs. For instance the CERN SPS accelerator was first upgraded into a proton antiproton collider, then a heavy ion accelerator, later a lepton injector for LEP and now a high density proton injector for LHC. The technical choices made in the LHC to deliver high performance while minimizing cost could drastically reduce the adaptability of the machine, since most of its elements are closely packed and embedded in a continuous cryostat. This is borne in mind by the designers, who make all efforts to include as much flexibility as possible in the lattice to allow further upgrades and cope with unpredictable demands.

Synchrotron radiation is significant in the LHC
In electron-positron colliders the particles loose every second through synchrotron radiation an amount of energy much larger than the beam stored energy. This loss must be continuously compensated by the RF system, and as a consequence this phenomenon limits the attainable energy while providing damping of particle oscillations. These effects are unimportant in the LHC because owing to the larger mass of the particles the energy radiated during the same time is only a tiny fraction of the beam energy. They will become significant in proton machines at much higher energies (around 100 TeV). However in the LHC the power emitted, about 3.7 kW, cannot be neglected as it has to be absorbed by the beam pipe at cryogenic temperature. This affects the installed power of the refrigeration system and is an important cost issue. In addition the synchrotron light impinges on the beam pipe walls as a large number of hard U.V. photons. These release absorbed gas molecules, which then increase the residual gas pressure, and liberate photo-electrons, which are accelerated accross the beam pipe by the strong positive electric field of the proton bunches. These photoelectrons add to the cryogenic load and may induce an instability of transeverse coupled bunch modes.



1.3 Magnets for the Large Hadron Collider
Magnificent magnets

The LHC will consist of two "colliding" synchrotrons installed in the 27 km LEP tunnel. They will be filled with protons delivered from the SPS and its pre-accelerators at 0.45 TeV. Two superconducting magnetic channels will accelerate the protons to 7-on-7 TeV, after which the beams will counter-rotate for several hours, colliding at the experiments, until they become so degraded that the machine will have to emptied and refilled. The magnetic channels will be housed in the same yoke and cryostat, a unique configuration that not only saves space but also gives a 25 % cost saving over separate rings. High energy LHC beams need high magnetic bending fields, because the machine radius was not a parameter which could have been increased to provide gentle curves. To bend 7 TeV protons around the ring, the LHC dipoles must be able to produce fields of 8.36 Tesla, over five times those used a few years ago at the SPS proton-antiproton collider, and almost 100,000 times the earth's magnetic field. Superconductivity makes this possible. This is the ability of certain materials, usually at very low temperatures, to conduct electric current without resistance and power losses, and therefore produce high magnetic fields. For comparable power consumption, the LHC can delivery 25 times the energy and 10,000 times the luminosity of the SPS collider.

Fine cables
LHC magnet coils are made of copper-clad niobium-titanium cables. This technology, invented in the 1960s at the Rutherford-Appleton Laboratory, UK, was first used in a superconducting accelerator at the Fermilab Tevatron in the US in 1987. The Tevatron magnets reach peak fields of 4.5 Tesla at 4.2 K. The electron-proton collider magnets at HERA, at the DESY Laboratory, Germany, go somewhat higher, to around 5.5 Tesla. To get beyond this, LHC magnets will be operated at 1.9 K above absolute zero, that is almost 300¡ C below room temperature. This unusually low limit puts new demands on cable quality and coil assembly. European industry is already delivering cables that can carry 15,000 amps at 1.9 K and withstand forces which build up to hundreds of tons per metre in the coils as the field rises.

Staying high
LHC magnet coils will be long, some 14 metres or more, and narrow, the inner diameter being 56 mm. Coil winding requires great care to prevent movements as the field changes. Friction can create normally-conducting "hot-spots" which "quench" the magnet out of its cold, superconducting state. A quench in any of the 5,000 LHC superconducting magnets will disrupt machine operation for several hours. Superconducting magnets have to be "trained" to reach higher and higher quench fields, as smaller and smaller "wrinkles" are removed from the coils. Individual training periods must be short for large scale production, for example for the 1,296 LHC dipoles. This puts tremendous demands on assembly control and testing. More energy is stored in a high magnetic field than in a low one, so the onset of a quench must be handled in a timely fashion. To design effective controls systems, safety engineers are using extremely advanced computer programmes to perform coupled mechanical-magnetic-thermal analyses of stresses induced by a quench. As well as dipoles, more than 2,500 other magnets are needed to guide and collide the LHC beams, ranging from small, normally conducting bending magnets to large, superconducting focusing quadrupoles. A special development programme is under-way in European laboratories and industry to build these novel, twin-channel quadrupoles. Operating superconducting installation on the scale of the LHC will provide valuable experience which could assist in some commercial developments where reliability is of vital concern. Superconducting cables could be used for low-loss transport of large amounts of electricity over long distances. The storage capacity of large superconducting coils operating at "comfortable" temperatures could be exploited to distribute the load on electricity generators more evenly between night-time and peak hours.

1.4 Cryogenics for the LHC

Keeping cool
The cryogenic technology chosen for the LHC was developed by the Commissariat a l'Energie atomique in Grenoble, and pioneered industrially for the Tore Supra fusion tokamak at Cadarache, France. It uses superfluid helium, which has unusually efficient heat transfer properties, allowing kilowatts of refrigeration to be transported over more than a kilometre with a temperature drop of less than 0.1 K. LHC superconducting magnets will sit in a 1.9 K bath of superfluid helium at atmospheric pressure. This bath will be cooled by low pressure liquid helium flowing in heat exchanger tubes threaded along the string of magnets. The reliability and efficacy of this sophisticated cryoloop are key factors in achieving the required magnet performance. The LHC cryogenic system is very large as well as very cold. Refrigeration power equivalent to over 140 kW at 4.5 K is distributed around the 27 km ring. To save costs, it is essential to reuse the four existing LEPII 12 kW, 4.5 K cryoplants. Their cooling power will be increased by 50% and 1.9 K stages will be added. Again for economic reasons, innovative technology is being sought for the helium compressors. Multi-stage, cold centrifugal compressors are needed and valuable input will be provided by present work at the Continuous Electron Beam Accelerator Facility CEBAF in the US, on a system at about on third LHC scale.

Avoiding trouble
In all, LHC cryogenics will need 40,000 leak-tight pipe junctions, 12 million litres of liquid nitrogen will be vaporised during the initial cooldown of 31,000 tons of material and the total inventory of liquid helium will be 700,000 litres.

Dal sito di Jaeri http://jkj.tokai.jaeri.go.jp/

The High Intensity Proton Accelerator Facility of the Japan Atomic Energy Research Institute

Tokai – Japan

1. INTRODUCTION

The high-intensity proton accelerator facility project in Japan was formed by joining together the Neutron Science Project (NSP) of Japan Atomic Energy Research Institute (JAERI) and the Japan Hadron Facility (JHF) Project of High Energy Accelerator Research Organization (KEK).

The facility will be constructed at the JAERI/Tokai site, as shown in Fig. 1.

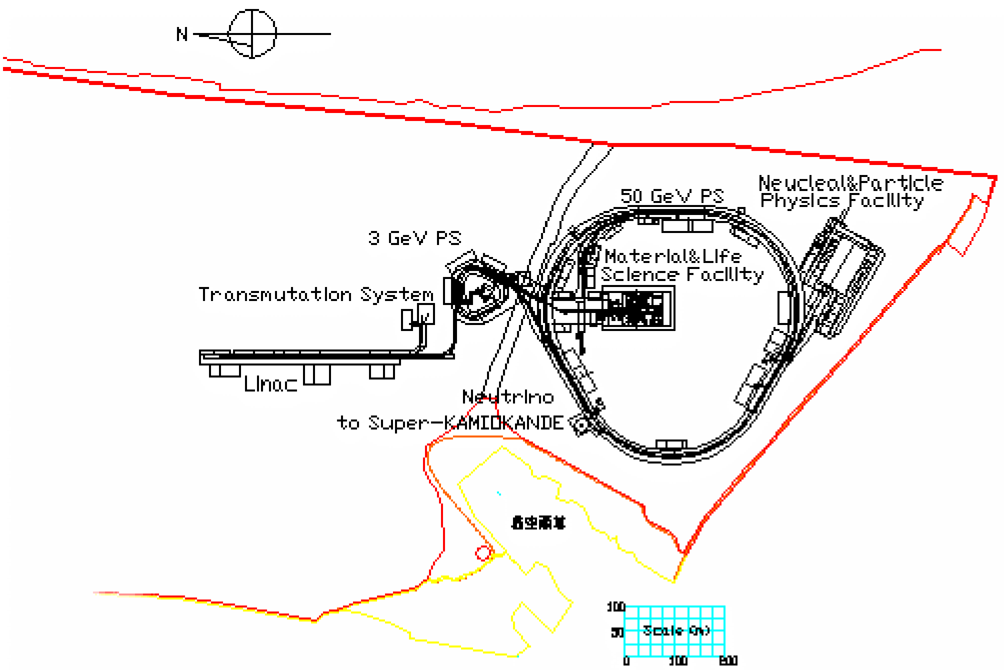


Figure 1

Phase-I of the project comprises a 600-MeV linac, a 3-GeV, 1-MW rapid-cycling synchrotron (RCS) and a 50-GeV main synchrotron. One half of the 400-MeV beam from the linac is injected to the RCS, while the other half is further accelerated up to 600 MeV by a superconducting (SC) linac. The 3-GeV beam from the RCS is injected to the 50-GeV synchrotron.

The 600-MeV beam accelerated by the SC linac is transported to the experimental area for an accelerator-driven nuclear waste transmutation system (ADS). The 3-GeV beam from the RCS is mainly used to produce pulsed spallation neutrons and muons. The muon-production target and the neutron-production target are, respectively, located in series in the Materials and Life Science Experimental Area. Ten percent of the beam is used for muon production. The 50-GeV beam is slowly extracted to the Particle and Nuclear Physics Experimental Area. It is also fast extracted for neutrino experiments, which are conducted at the SUPERKAMIOKANDE detector located 300-km from the Tokai site.

In this way, a wide variety of science and engineering fields will be intensively and efficiently promoted by the high-power proton accelerators. The Phase-I facility includes upgradability to a 5-MW neutron source, which is allocated to Phase II of the project.

The Accelerator Baseline schedule is shown in Fig. 2.

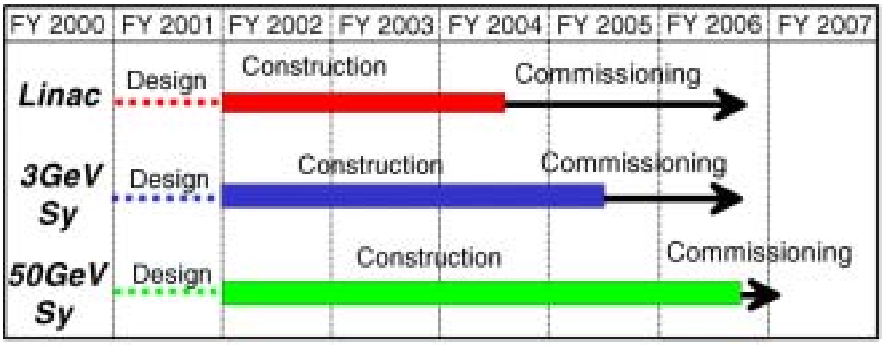

FY 2000
FY 2001
FY 2002
FY 2003
FY 2004
FY 2005
FY 2006
FY 2007
Linac
Design
Construction
Commissioning
3GeV Sy
Design
Construction
Commissioning
50GeV Sy
Design
Construction
Commissioning

Figure 2

2. LINAC

The linac uses normal-conducting cavities up to 400 MeV, while it uses superconducting cavities (SCC) from 400 to 600 MeV, as shown in Fig. 3.

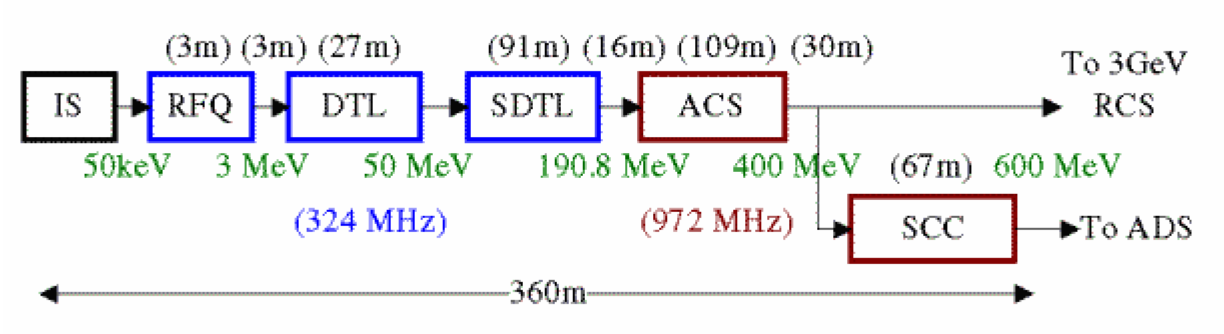


Figure 3

Linac parameters (updated: 11/14/2000)	
Accelerated particle	H^-
Energy	450 MeV
Repetition	50 Hz
Beam Pulse Length	500 microsec
Chopping Rate	54%
RFQ, DTL, SDTL Frequency	324 MHz
CCL Frequency	972 MHz
Peak Current	50 mA
Linac Average Current	675 microA
Average Current after chopping	338 microA
Total Length	360 m

A volume-production type of negative hydrogen source (Fig. 4) is designed to produce a peak current of 53 mA with a pulse length of 500 ms and a repetition rate of 50 Hz. About 53 percent of the beam will be accelerated after the beam is chopped at both the 50-keV low-energy beam transport (LEBT) and the 3-MeV medium-energy beam transport (MEBT).

Figure 4

ION SOURCE

Particle	H^-
Type	Volume Production
Peak Current	32 mA
Normalized Emittance (90%)	0.6 pi mm mrad
Extraction Energy	50 KeV

A radio-frequency quadrupole (RFQ) linac (Fig. 5) accelerates the beam up to 3 MeV, a conventional drift-tube linac (DTL) up to 50 MeV (Fig. 6), and a separated DTL (SDTL) up to 200 MeV (Fig.7).

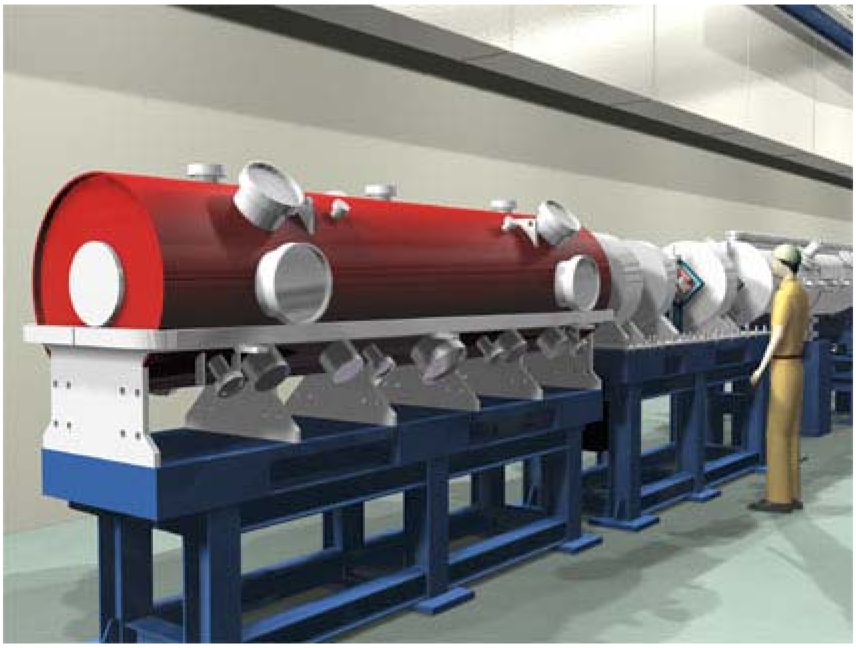


Figure 5

RFQ

Energy	3MeV
Frequency	324 MHz

An acceleration frequency of 324 MHz is the highest-possible one, for which the 3-MeV drift tubes can accommodate electromagnetic quadrupoles.

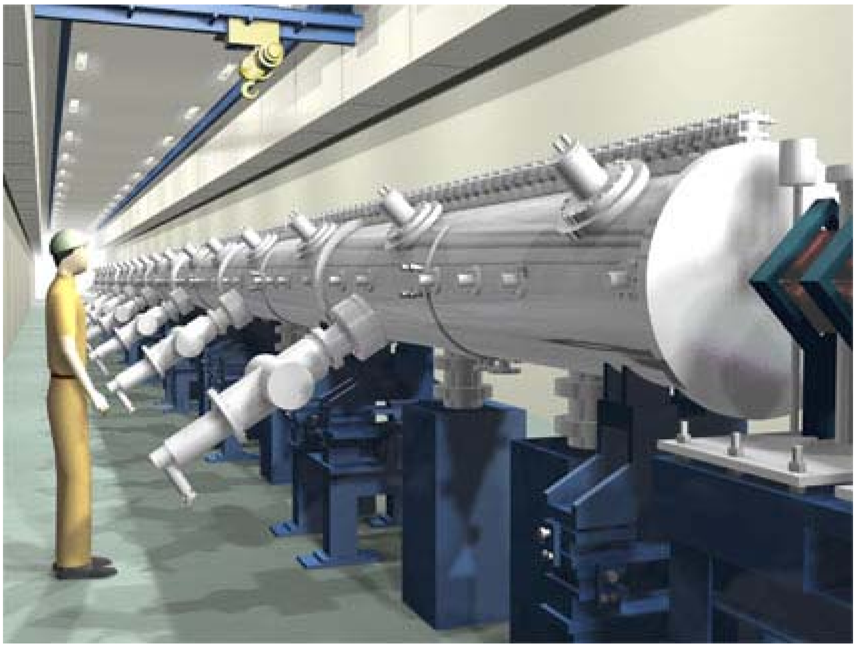


Figure 6

DTL

Energy	50MeV
Frequency	324 MHz
Focusing Quadrupole Magnet	Electromagnet
Total Tank Length	27 m
The Number of Tanks	3

The higher frequency is the more preferable for obtaining a higher peak current by more frequent focusing. The electromagnetic-quadrupole system obviously keeps much more knobs than the permanent magnet system. This frequency is nearly the lowest-possible one for the use with klystrons, practically speaking. The frequency is increased by a factor of three at 200 MeV, which is sufficiently high for acceptable adiabatic damping of the bunch length by the high-energy linac.

Figure 7

SDTL

Energy	200MeV
Frequency	324 MHz
Total Tank Length	71 m
The Number of Tanks	34

Among the possible candidates for the coupled-cavity linac to be used from 200 MeV to 400 MeV, the annular-ring coupled structure (ACS) is the most preferable owing to its axial symmetry (Fig. 8). Several prototypes of the L-band ACS have been developed and powered up to higher than the designed value for the Japanese Hadron Project (JHP). Test machining and brazing of the 972-MHz version of the ACS is now in progress.

Figure 8

ACS

Energy	200-400MeV
Frequency	972 MHz
E_0	4.3 MV/m
Total Tank Length	27 m
The Number of Tanks	46
Number of klystrons	23

2. 3 GeV RING

The high intensity proton accelerators are proposed for the joint project between JAERI and KEK. In this project, there is a rapid cycling proton synchrotron at a repetition rate of 25 Hz, where 8.3 x 10^{13} protons will be accelerated from 400 MeV to 3 GeV within 20 ms, then an average beam power of 1 MW at 3 GeV will be produced for neutron experiments and it is also provided to 50 GeV Proton Synchrotron.

In figure 9 it is possible to see a schematic view of the 3 GeV Ring.

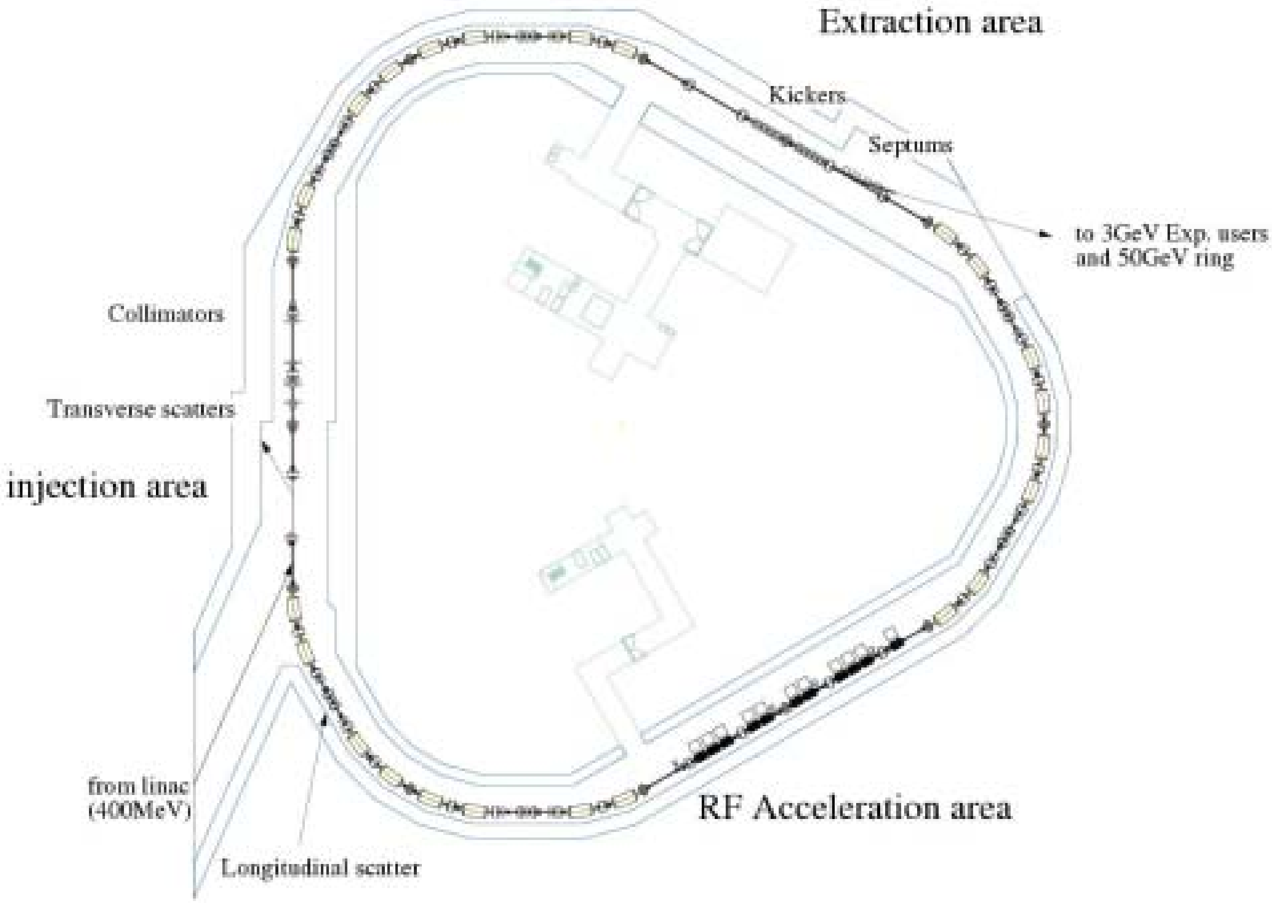


Figure 9

Main parameters of 3 GeV PS (Since the designs of injection and extraction system are brushed up now, some minor revisions will be performed ASAP)	
Injection Energy	400 MeV
Extraction Energy	3 GeV
Beam Intensity	8 x 10^{13} ppp
Repetition Rate	25 Hz
Average Beam Current	333 microA
Beam Power at 3 GeV	1 MW
Circumference	313.5 m
Magnetic Rigidity	3.18-12.76 Tm
Lattice Cell Structure	3-Cell DOFO x 2 module + 3-Straight Cell
Typical Tune	Hor. 7.35, Vert. 5.8
Momentum Compaction Factor	0.013
Total Number of Cells	27
The Number of Bending Magnets	24
Magnetic Field	0.27-1.1 T
The Number of Quadrupoles	60
Maximum Field Gradient of Q-Mag.	5 T/m
Harmonic Number	2
RF Frequency	1.36-1.86 MHz
Accelerating Voltage	421 kV(Max.)
RF Voltage/Cavity	43 kV(Max., Field Gradient of 26 kV/m)
The Number of RF Cavities	10
Average Circulating Beam Current	9-12.4 A
Beam Emittance at Injection	144 pi mm mrad
Beam Emittance at Extraction	54 pi mm mrad