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Status of CERN

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Abstract

The European Organisation for Nuclear Research (CERN) operates one of the largest laboratories in High Energy Physics in Geneva, Switzerland. It serves more than 5000 users of whom the main fraction comes from Europe. It is financed by the 20 European Members States but receives also major contributions from the USA, Japan and Russia for the construction of the Large Hadron Collider (LHC) which will provide proton - proton collisions with a centre-of-mass energy of 14 TeV. In addition, substantial contributions to LHC are made by Canada and India. A large number of states participates in the financing of the detectors used in the general and LHC physics programmes, CERN providing only a fraction of this budget.
Given the importance of the contribution of Japan, Russia and USA, these states have observer status at the CERN Council and participate in the sessions of the Committee of Council when dealing with LHC matters. Further observer states are the European Union, Israel and Turkey.
A summary of the accelerator complex is given in point 2 and of the physics programme in point 3. The present and planned accelerator R&D is outlined in point 4.

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Abstract

An overview of the present CERN facilities is given and their planned development is outlined as required by the approved physics programme.

Although the main task of CERN in the next years will be the construction of LHC, a small but significant programme for accelerator R&D has been defined. It comprises a multi-TeV linear collider, advanced neutrino beams and the upgrading of LHC.

1 INTRODUCTION

The European Organisation for Nuclear Research (CERN) in Geneva, Switzerland, operates one of the world's largest laboratories in High Energy Physics. It serves more than 5000 users, the majority of which comes from Europe. It is financed by 20 European Members States but also receives major contributions from the USA, Japan and Russia for the construction of the Large Hadron Collider (LHC) which will provide proton - proton collisions with a centre-of-mass energy of 14 TeV. In addition, substantial contributions to LHC are made by Canada and India. A large number of states participate in the financing of the detectors used in the general and LHC physics programmes, with CERN providing only a fraction of this budget.

Given the importance of the contributions of the USA, Japan, and Russia, these states have an observer status at the CERN Council and participate in the Committee of Council sessions that deal with LHC matters. Further observer states are the European Union, Israel and Turkey.

A summary of the accelerator complex is given in point 2 and of the physics programme in point 3. The present and planned accelerator R&D is outlined in point 4.

2 THE ACCELERATORS

The first element of the proton accelerator chain is a 50 MeV linac (L2), followed by the four-ring PS Booster (PSB) and the CERN Proton Synchrotron (CPS) providing up to 24 GeV/c protons either directly to the experiments or 14 GeV/c protons to the 400 GeV Super Proton Synchroton (SPS).

The PSB synchrotron has recently been upgraded from 1 to 1.4 GeV for LHC to overcome the space charge limit at PS injection[1]. This has also had a beneficial effect for ISOLDE which is a facility where radio-active ions are investigated. These ions are produced in special targets of the PSB beam. Fig. 1 shows a schematic view of the CERN accelerators.

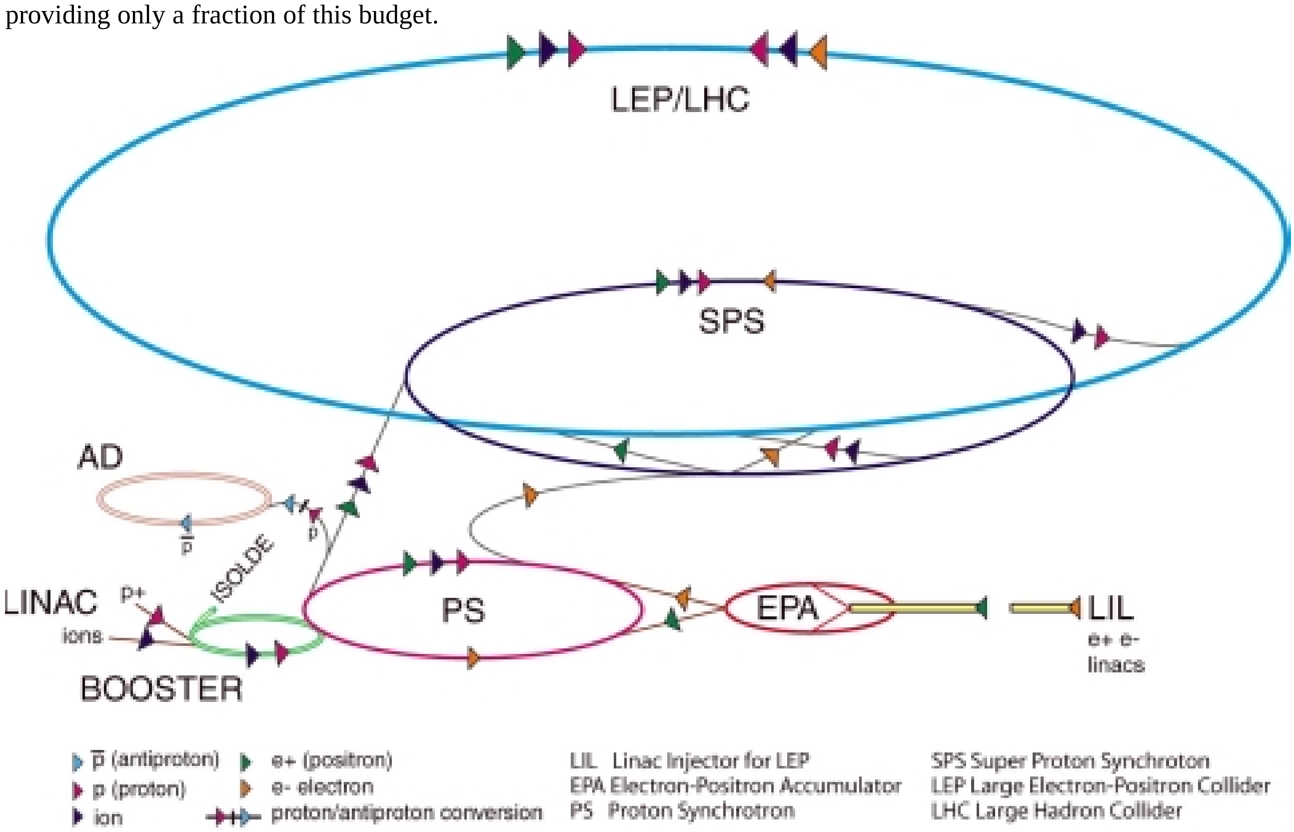

Fig. 1 - CERN's chain of accelerators in 2000

After the closure of the West Area Neutrino Facility (WANF) at the SPS, a new muon neutrino beam providing CERN muon Neutrinos to Gran Sasso (CNGS) is under construction. The facility consists of a 400 GeV proton beam line, a carbon target, pulsed magnetic horn and reflector focusing pions at about 30 and 60 GeV towards Gran Sasso, and a 2.45 m diameter, 1 km long evacuated tube in which pions and kaons can decay and which is terminated by a hadron stop. The muon neutrinos continue for 730 km with an average energy of 18 GeV to the Gran Sasso National Laboratory of INFN for a long baseline experiment. The layout is shown in Fig. 2. The facility will be operational in 2005[2].

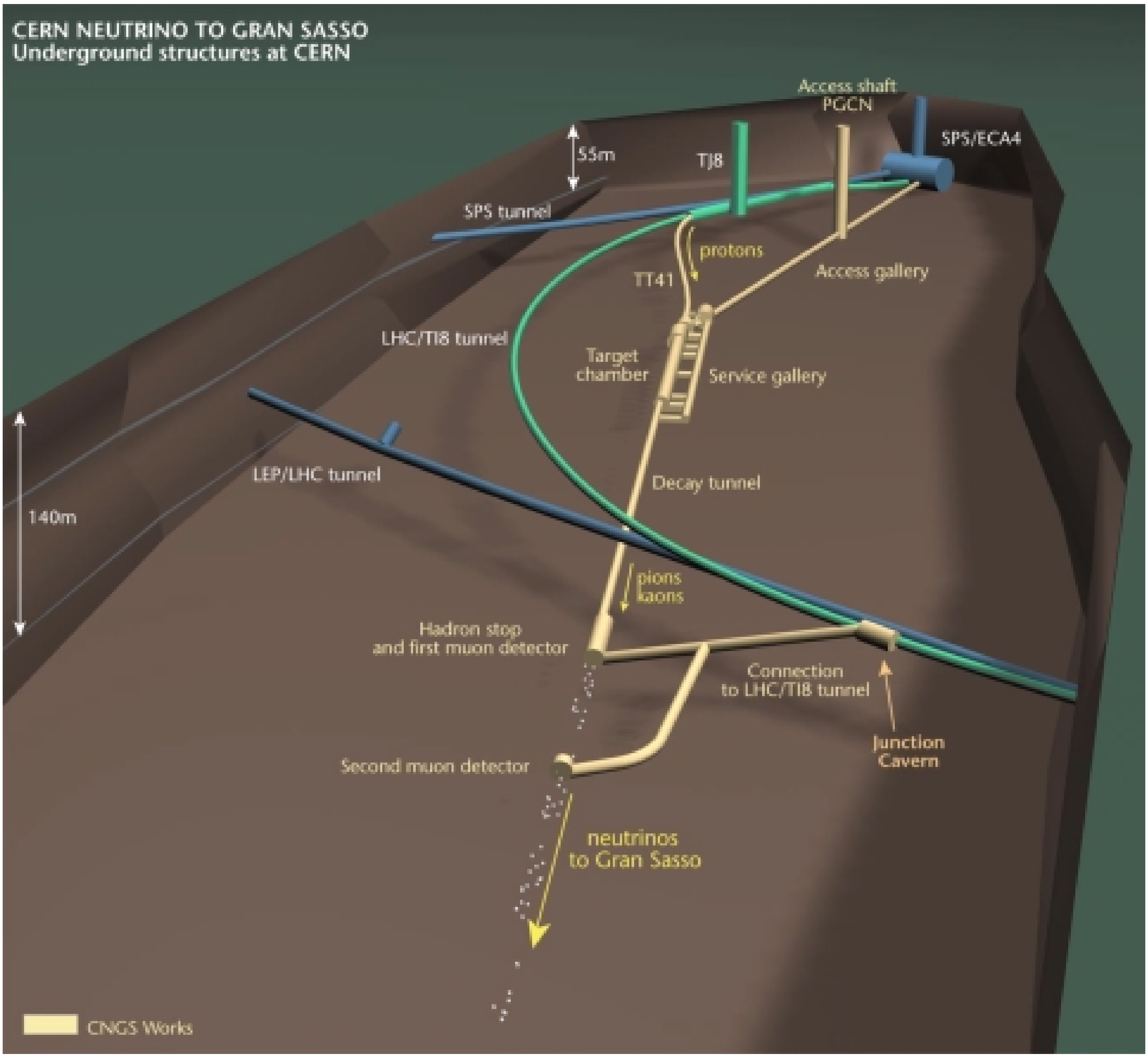

Fig. 2 - The CNGS layout

This accelerator chain is also used with ions. Initially, in 1992, Sulphur ions were accelerated. Since 1994, after the construction of a special linac (L3), lead ions can be accelerated up to 158 GeV/u. This linac including the ion source and the RFQ was constructed by a collaboration between GSI/Germany, LNF/INFN/Italy, GANIL/France, and CERN with contributions from institutes in India and Switzerland [3].

The CPS also provides a proton beam at 24 GeV/c to produce antiprotons at 3.5 GeV/c which are stored in the Antiproton Decelerator (AD) ring and subsequently decelerated to 5.6 MeV (100 MeV/c). In order to keep the emittance within reasonable bounds, rf deceleration alternates with stochastic and electron cooling. This new ring is built mainly from components of the Antiproton Collector (AC) ring which was decommissioned after the first phase of CERN's antiproton programme in 1996. The AD was commissioned in 1999 and has now been in operation since the summer 2000 [4]

The AD experiments normally decelerate antiprotons further by degrader foils to accumulate them at very low energy in magnetic traps. However, this process is not very efficient. In order to improve the yield for the traps, a decelerating RFQ (RFQD) has been constructed which obtains antiprotons at an energy which can be set between 20 and 100 KeV. This device has been commissioned and transfer efficiencies of 30 % (44 % design) have been achieved in the first preliminary measurements [5].

The Large Electron Positron (LEP) collider was operating at a beam energy of 46 GeV (Z_0 resonance) from 1989 to 1995. The beam energy has been increased gradually since 1995 and has reached 104 GeV in 2000[6]. This has been achieved by building up a powerful superconducting rf system which eventually provided 3.6 GV together with the remaining part of the Copper rf system (0.12 GV). The superconducting rf system consisted finally of 288 cavities (272 Nb-film on Cu, 16 Nb bulk). It operated surprisingly well at an average gradient of 7.4 MV/m (Nb film system)[7] though it had been designated for 6 MV/m.)[8].

In order to make space for the LHC which will be installed in the LEP tunnel (27 km circumference), LEP dismantling started in December 2000 and will take a good fraction of 2001. The LHC is under construction and all major components are in production. The running-in will start at the beginning of 2006 and a first physics run of seven months with protons is planned to start in summer of that year. The latter run will be followed by a run with lead ions lasting about six weeks in 2007 [9].

The injector chain has to be upgraded for LHC operation. The PS complex upgrade for protons is nearly complete and the specified beam parameters have been successfully obtained[1]. In order to obtain lead ion bunches of sufficient intensity for LHC, a Low-Energy Ion Ring (LEIR) has to be constructed in the next years which will act as a buffer between the fast-cycling linac (L3) and the slow-cycling PSB. It will use most of the components of the Low-Energy Antiproton Ring (LEAR) which was decommissioned in 1996 after the first phase of CERN's antiproton programme.

3. THE PHYSICS PROGRAMME

The scope of the CERN physics programme is very broad. It ranges from the preparation of experiments with the LHC to experiments with anti-hydrogen virtually at rest at AD[10].

At the moment, 26 experiments are approved not counting the 56 approved experiments with radio-active ions at ISOLDE. The results from the four LEP experiments (ALEPH, DELPHI, OPAL and L3) are being analysed and the detectors are being dismantled.

Four large LHC detectors (ALICE, ATLAS, CMS and LHCb) are being constructed by truly global collaborations and will start data taking in 2006.

The fixed-target programme has been much reduced to free resources for LHC. At present, twelve experiments are approved and are all located in the North Area of the SPS. The slow-extracted (5 s spill) proton beam is used by NA 48 to study CP-violation in the K-meson system, and COMPASS to investigate hadron structure with polarised muon beams, in particular, the gluon polarisation in a longitudinally polarised nucleon. The slow-extracted fully stripped lead ions are used at either 40, 80 or 158 GeV/u by a number of experiments searching for quark-gluon plasma.

At the PS complex, three experiments are approved. The East Hall houses DIRAC an experiment measuring the lifetime of the $\bullet^{+}\bullet^{-}$ atoms to test low-energy QCD predictions, and HARP measuring precisely the yield of 2 to 15 GeV/c protons and pions with a variety of targets, which is of great relevance for the design of targets for advanced neutrino beams. The third experiment PS 213 starting in 2001 will use the new nTof facility at the PS where a neutron beam is generated in a lead target by single bunches of 24 GeV/c protons. Using time-of-flight methods and a 190 m long flight path neutron-induced nuclear reactions can be studied with an extremely high energy-resolution. The facility is housed in a transfer tunnel originally built to transfer protons from the CPS to the West Hall of the SPS.

Three experiments are approved at the AD which provides antiprotons at 100 MeV/c. Their principal aim is to produce anti-hydrogen by combining the cooled antiprotons with positrons in traps and to compare its spectroscopy with that of hydrogen. This should provide a very sensitive test of the CPT theorem.

The ISOLDE facility produces radio-active ions using 1.4 GeV protons from the PSB for 56 approved experiments which range from studies of weak interactions and nuclear physics (46 %), solid state physics (23 %), atomic physics (17 %), particle and astrophysics (11%), to biology and medicine (3 %).

A particular and unique feature of CERN is that it provides free-of-charge, a large variety of high-energy test beams to the global community in particular for tests of LHC detector components but also for many other experiments including space-based detectors. These test beams are derived from targets in the 400 GeV slow-extracted proton beam which can be shared between the North and the West Hall of the SPS. Four beam lines exist in the North Hall and two in the West Hall with two to three positions for experiments along the beam lines. The experiments have to alternate but with muons simultaneous operations of two test set-ups is possible. The PS East Hall offers five beam lines which are all used for LHC detector tests.

4. ACCELERATOR R&D

This is only a brief summary, as it is covered by other contributions at this conference.

4.1 LHC

In the past, the main thrust for LHC has been focused on the development of the 9T (8.35T nominal) superconducting magnets and the 2K cryogenic system. This programme is concluded and the major components are in production [9].

However, in order to exploit fully the investment and the potential of LHC, studies have started with a view to increasing the luminosity of LHC from the nominal 10^{34} cm^{-2} s^{-1} per experiment to $10^{35}cm^{-2}$ s^{-1}. Four measures can be envisaged [11] :

i) increase the beam currents until the beam-beam limit is reached, which is expected to happen around 2.5 x 10^{34} cm^{-2} s^{-1} ;

ii) increase the focusing at the interaction points by lowering β^* from 0.5 m to 0.25 m which should increase the luminosity by a factor 2 leading potentially to 5 x 10^{34} cm^{-2} s^{-1}. This requires insertion quadrupoles of larger aperture and, in turn, new superconducting cable instead of the NbTi cable foreseen for the first-generation quadrupoles, so that a higher magnetic field can be sustained in the coils. To this end, R&D on Nb_3Sn cable has been undertaken in collaboration with the University of Twente in the Netherlands and research on Nb_3Al cable has been commissioned in Japan through KEK.

iii) An additional step could be doubling the number of bunches which could lead to a further factor 2 and a luminosity close to $10^{35}cm^{-2}$ s^{-1} provided the adverse effects [12] of more and enhanced parasitic crossings of the bunches can be controlled. It has the advantage that it does not decrease the luminosity lifetime and the number of events per bunch crossing stays constant. However, the time resolution of the detectors will need improvement as the bunches will be spaced 12.5 ns instead of 25 ns.

iv) the luminosity can also be increased by raising the beam currents provided the dynamic aperture is sufficient to accommodate larger beam emittances. The latter must be blown up to respect the beam-beam limit. Obviously, this measure can only be envisaged after a number of years of operation when the behaviour of the storage ring has been sufficiently studied and understood.

4.2 Superconducting rf cavities

This is a research line at CERN which has been pursued since the 1960's. It has been the basis for the industrial construction of the superconducting LEP rf system which eventually enabled LEP to reach 104 GeV per beam.

This R&D has continued all the time at a modest scale mainly to explore the potential of the Nb-film technique developed at CERN. Since the cavities are made from copper, this technique makes them more mechanically stable than Nb-bulk cavities and the high thermal conductance of copper makes them virtually quench-free. However, accelerating gradients until now have remained below the gradients achievable with Nb-bulk [13].

The Nb-bulk cavities, however, have reached even higher gradients with surface treatment called electro-polishing and developed at KEK. Single cells prepared with this technique in a collaborative effort between DESY, CEA/Saclay and CERN have reached gradients in excess of 35 MV/m, reproducing the results of KEK where even 40 MV/m has been achieved [14].

4.3 CLIC

CERN has studied in parallel to the LHC a Compact Linear Collider (CLIC) operating at 30 GHz. Recent studies concentrate on a collider with a centre-of-mass energy of 3 TeV with a luminosity of $10^{35}cm^{-2}$ s^{-1} to reach beyond the LHC physics. In order to make it very compact a high acceleration gradient of 150 MV/m has been chosen which makes the facility relatively short, and rf power is provided by a second, low-energy (1.2 GeV) electron beam running in parallel with the electron and positron main beam so that a small diameter tunnel is sufficient. This second beam, the drive beam, is decelerated in special 30 GHz structures converting the kinetic energy of the drive beam into about 400MW/m rf power. Once the energy of the second beam is as low as 0.12 GeV it must be dumped and replaced, which happens every 600 m [15,16].

A number of test facilities [17] have been constructed and a new CLIC Test Facility (CTF3) is under design and construction will start in 2001. This new test facility will be built on the premises of the LEP pre-injector consisting of the linac LIL and the accumulator EPA (see Fig. 1) which will be decommissioned in 2001. Many of the components from these accelerators will be reused. The drive beam generation scheme will be tested in CTF3 and the drive beam will be used to demonstrate acceleration with 150 MV/m. In parallel, the development of critical components will continue. Since rf conditioning and testing of components is indispensable for this R&D, the availability of a 30 GHz rf source before operation of CTF3 would be very desirable. The most promising source at present appears to be a gyroklystron.

4.4 Advanced neutrino beams

Already during the design phase of the CERN neutrino beam to Gran Sasso, the possible upgrade of the performance of CNGS has been considered. This upgrading will require an improved performance of the proton accelerator chain and of the target.

A more powerful injector of the PS than the present one consisting of the linac L2 and the PSB booster synchrotron would certainly improve the proton accelerator chain. For this reason, a new more powerful linac using the superconducting LEP cavities was considered some time ago [18]. In the framework of the recent study of a neutrino factory [19], a new conceptual design for this 2.2 GeV Superconducting Proton Linac (SPL) providing 4 MW beam power has been made [20].

The next step will be a quantitative study of its impact on PS and SPS performance. SPL is also of interest for an upgrade of ISOLDE. Note, however, that it cannot improve the performance of LHC as the latter is limited by the beam-beam effect.

The HARP experiment at the PS will precisely measure the pion yield of 2.2 GeV protons in order to verify whether this proton energy is sufficient for the pion production required for the neutrino factory. The answer should be available by the end of 2001.

Before proceeding to a fully-fledged neutrino factory, it is interesting to consider the neutrino beam generated by these low-energy protons provided that the 4 MW on target can be achieved. It has been shown that this muon neutrino beam would have a very low contamination with electron neutrinos and, therefore, would be suited for the search for oscillation between muon neutrinos and electron neutrinos [21].

The CERN study of a neutrino factory [19] is based on SPL feeding an accumulation ring with multi-turn injection (660 turns) so that the linac pulse (2.2 ms) is compressed into a train (3.2 μs) of 140 bunches. In order to obtain short bunches the beam is transferred to the compressor ring where the bunches are shortened from 3.5 to 1 ns r.m.s. length by bunch rotation with a suitable rf system. This takes less than 10 turns. It is assumed that these two rings could be housed together in the CERN ISR tunnel which has a circumference of about 1 km.

The bunch train is then fast-extracted and hits a target of two interaction lengths. Muons resulting from the decaying pions are collected at an average energy of 300 MeV/c and enter rf cavities for phase rotation 30 m downstream of the target followed by a transverse cooling section which consists of a sequence of absorber and rf cavities (44 and 88 MHz). A final set of 88 MHz cavities plus a set of 176 MHz cavities accelerates the muons to 2 GeV which is the injection energy of the first recirculator.

After acceleration to 10 GeV, the beam is transferred to a second recirculator which raises the beam energy to 50 GeV. The muon storage ring has a bow-tie shape in order to have two long straight sections and, therefore, two neutrino beams generated by the decaying muons. The neutrino beams would be directed towards detectors at about 1000 and 3000 km.

The CERN scheme which uses a pulsed horn for the pion collection and rf for phase rotations compares well in first approximation with the schemes developed in Japan and in the US[22]. However, much more simulation and development work is required before this comparison can be put on a solid basis. The most critical items are the target and the muon cooling. Both require a considerable R&D effort which probably can only be tackled by international collaboration given the scale of effort required.

5. CONCLUSIONS

CERN concluded the LEP Programme in 2000 and LEP is being dismantled in 2001. All effort is concentrated on the construction of the LHC accelerator and the associated detectors which will start data taking in 2006. Significant contributions are being made to the accelerator by a number of Non-Member States.

The fixed-target programme has been reduced and refocused. The construction of a new neutrino beam for a long-baseline experiment together with the Gran Sasso National Laboratory in Italy has been approved.

A small but significant R&D programme covers the study of LHC luminosity upgrading, a multi-TeV linear electron-positron collider and a possible future neutrino programme offering more powerful neutrino beams.

Given the complexity and challenges of the linear collider and the neutrino factory, a great variety of R&D issues have to be tackled. Since substantial resources are required to make real progress, CERN seeks to join forces with other laboratories engaged in this type of R&D in order to advance the field and to prepare a global approach.

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