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Deliberation Document on the European Strategy for Particle Physics

The European Strategy Group

(Edited by the Scientific Secretariat for the European Strategy Session of the Council)

The first European Strategy for Particle Physics (the Strategy), consisting of 17 Strategy Statements, was adopted by the CERN Council at its special session in Lisbon in July 2006. A proposal for the updated Strategy has been formulated by the European Strategy Group (ESG) during the five-day meeting in Erice in January 2013. The ESG was assisted by the Preparatory Group, which had provided scientific inputs. Those inputs were based on the material presented at the two-and-half-day Open Symposium, which took place in Krakow in September 2012, and on documents submitted by the worldwide community.

This deliberation document describes the background information which leads to the Strategy Statements. For some organisational matters, suggestions to the CERN Council for possible modifications are formulated as well. The structure of the updated Strategy Statements follows closely the 2006 one: **Preamble** followed by two statements on **General issues**, four statements on **High-priority large-scale scientific activities**, five more scientific statements on **Other scientific activities essential to the particle physics programme**, i.e. ingredients mandatory for the healthy development of particle physics, two statements on **Organisational issues** concerning the position of the CERN Organization in the context of the worldwide particle physics community and other European organisations, and three statements on **Wider impact of particle physics** related to outreach and communication of physics results, knowledge and technology transfer to society and industry, and particular importance of engineering education. The last Strategy Statement, **Concluding recommendations**, concerns the update and implementation of the Strategy. Each Strategy Statement gives a short description of the issue followed by an action list in italic characters.

Preamble

> Since the adoption of the European Strategy for Particle Physics in 2006, the field has made impressive progress in the pursuit of its core mission, elucidating the laws of nature at the most fundamental level. A giant leap, the discovery of the Higgs boson, has been accompanied by many experimental results confirming the Standard Model beyond the previously explored energy scales. These results raise further questions on the origin of elementary particle masses and on the

> role of the Higgs boson in the more fundamental theory underlying the Standard Model, which may involve additional particles to be discovered around the TeV scale. Significant progress is being made towards solving long-standing puzzles such as the matter-antimatter asymmetry of the Universe and the nature of the mysterious dark matter. The observation of a new type of neutrino oscillation has opened the way for future investigations of matter-antimatter asymmetry in the neutrino sector. Intriguing prospects are emerging for experiments at the overlap with astroparticle physics and cosmology. Against the backdrop of dramatic developments in our understanding of the science landscape, Europe is updating its Strategy for Particle Physics in order to define the communitys direction for the coming years and to prepare for the long-term future of the field.

The original Strategy adopted in 2006 was elaborated before the start of LHC operations, while valuable operational experience is now available. There was no indication of the Higgs particle at the Tevatron. The international effort on the design studies for the International Linear Collider (ILC) was making steady progress, but there was no concrete indication of a country expressing strong interest to host the facility, and there was no conclusive prediction for the energy where interesting phenomena would appear: Thus, it was difficult to justify the construction of an e^+e^- collider. While various ideas on how to construct the next generation of long-baseline neutrino beams were being discussed, the value of the mixing angle θ_{13} had to be known in order to set a justifiable goal for new facilities. For those reasons, the Strategy was largely at the level of encouraging R&D in order to ensure the engineering readiness for making a decision when physics results would show the direction.

It was foreseen that the Strategy be regularly updated at an interval of about five years. The timing of this first update was delayed in order to wait for the first physics output from the LHC data collected at 7-8 TeV centre-of-mass energies. The discovery of the Higgs particle with a mass of 125 GeV has made the investigation of its properties one of the highest priorities. Furthermore, sufficient experience in operation was gained such that credible luminosity upgrade plans can be formulated for both machine and detectors. Several neutrino experiments have measured θ_{13}, allowing to design the next generation neutrino experiments with long-baseline beams using the conventional neutrino production technology. Such projects are now being discussed in Europe, Japan and the US. Another development concerns the ILC, for which a Technical Design Report has been completed and there is an initiative by the Japanese high-energy physics community to host it in Japan, with the initial goal to study the Higgs particle in a complementary way to the LHC. In addition to those scientific developments, the CERN Council gained enough experience as a body coordinating particle physics in Europe in order to consolidate the current organisational structure for implementation of the Strategy and its monitoring.

General issues

> a) The success of the LHC is proof of the effectiveness of the European organi-

sational model for particle physics, founded on the sustained long-term commitment of the CERN Member States and of the national institutes, laboratories and universities closely collaborating with CERN. *Europe should preserve this model in order to keep its leading role, sustaining the success of particle physics and the benefits it brings to the wider society.*

The leading role of Europe in particle physics, presently witnessed by the success of the LHC, relies heavily upon the underlying organisational model. At the root of this model is the existence of CERN, an international organisation running a world-leading laboratory, and coordinating a large community of strong particle physics communities all around Europe, working towards common scientific goals in universities, laboratories and national institutes. At the root of this model is the existence of CERN, a robust international organisation running a world-leading laboratory, based on a strong community of particle physicists working towards common scientific goals in universities, laboratories and national institutes. DELETE This model is built upon a true spirit of collaboration at the international level. On a wider perspective, this also promotes the scientific culture and the European openness in society. As the scale of the frontier machines and experiments increases, the time span of large-scale scientific projects in accelerator-based particle physics, from conception to data analysis, extends over several economic and political cycles. Long-term planning and stability of funding, through the sustained commitment of the CERN Member States, the Candidate for Accession and Associate States, and of the national funding agencies, are essential to maintain and strengthen the present success.

b) The scale of the facilities required by particle physics is resulting in the globalisation of the field. *The European Strategy takes into account the worldwide particle physics landscape and developments in related fields and should continue to do so.*

The increase in scale of the leading particle physics facilities results in the decrease of their number worldwide and the globalisation of the field. The timely realisation of complementary large-scale projects in different regions of the world, each of them unique in pushing further one of the well-identified frontiers of particle physics, is essential for the global progress of the field, as well as for the preservation and the development of its key technologies. This Strategy thus takes into account this international aspect, by involving the leading particle physicists from all regions of the world in the discussion and by contributing with its planning to the optimal use of the financial and human resources available worldwide, with long-term benefits to particle physics.

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

> c) The discovery of the Higgs boson is the start of a major programme of work to measure this particles properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europes top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*
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> d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.*
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> e) There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*
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> f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading neutrino projects in the US and Japan.*

The Strategy has to strive for a balance between maintaining the diversity of the scientific programme, which is vital for the field since a breakthrough often emerges in unexpected areas, and setting priorities since the available resources are limited. As already described, large-scale particle physics activities require substantial investment of human and financial resources for an extended period. Although many of these activities are important for particle physics, they require careful planning and prioritisation in the international context. Out of the many motivated proposals put forward by the community and described in the Briefing Book, only four activities have been identified as carrying the highest priority.

The key question of particle physics that should receive soon a definite answer was already identified by the 2006 Strategy: Whether the Standard Model of strong and electroweak interactions, with its minimal realisation of the Brout-Englert-Higgs mechanism of electroweak gauge symmetry breaking and the modifications required to account for neutrino oscillations, is a valid description up to energy scales much higher than the TeV scale, or is modified by the presence of new particles at energies accessible to present and future high-energy colliders.

Today, some essential milestones along these lines have already been reached: First, and most important, a new boson with mass near 125 GeV has been discovered, compatible with the scalar particle of the Standard Model within the present experimental errors; second, many particles, suggested by motivated extensions of the Standard Model with or without supersymmetry, have been excluded well beyond the previous LEP and Tevatron limits; finally, several new precision tests have confirmed the Standard Model description of flavour mixing and CP violation in the quark sector and established additional strong indirect constraints on possible new physics at the TeV scale and beyond.

On the one hand, the net result of all this is an impressive consolidation of the Standard Model of strong and electroweak interactions, with the technical possibility of extending its validity to scales much higher than the TeV scale. The simplest attempts to modify the Standard Model at the TeV scale, for example TeV-scale supersymmetry or partial compositeness, in order to correct some of its perceived theoretical weaknesses have started to be seriously challenged. On the other hand, there is strong evidence that the Standard Model must be modified, with the introduction of new particles and interactions, at some energy scale. Such evidence comes from studies of neutrino oscillations, dark matter, the observed baryon asymmetry of the Universe, the need to eventually incorporate quantum gravity and a model for cosmological inflation. Also, there are good indications that some of these modifications could take place in the vicinity of the TeV scale. Firstly, the theoretical concept of naturalness suggests that the validity of the Standard Model cannot extend much beyond the mass of its scalar particle. Secondly, weakly interacting particles with masses close to the TeV scale are among the leading candidates for dark matter. Moreover, the unification of gauge couplings at a very high energy scale can be achieved with supersymmetric spectra different from those of the simplest models and compatible with the present LHC bounds.

When facing this puzzle, it should be kept in mind that the exploration of the TeV scale and its vicinity is just the beginning. The completion of this exploration, which may end up either with the discovery or with the firm exclusion of new physics near the TeV scale, will require additional decades of efforts at the LHC and new facilities. These additional investigations are essential because each of their possible eventual outcomes will deeply affect our view of the fundamental laws and of symmetries in Nature. The main physics goals are clear: 1) push further the tests of the Standard Model at the energy frontier, in particular by measuring the properties of the newly- discovered Higgs particle and of the longitudinal components of the massive vector bosons with the highest possible precision, with the aim of establishing whether there are any deviations from the Standard Model predictions; 2) check whether the Higgs particle is accompanied by other new particles at the TeV scale, which could play a role in the global picture of electroweak symmetry breaking or in the solution of the dark matter puzzle. As reflected in three of the four high-priority activities, both hadron and lepton colliders at the high-energy frontier can play essential and complementary roles in this quest.

In the next decade, the LHC is the unique machine where this physics programme can be pursued. Running at its design energy and luminosity until about 2021, the LHC should deliver an integrated luminosity of about 300 fb^{-1} to the ATLAS and CMS experiments. By then, many replacements to the machine and the detectors will be required to continue operations. A series of improvements to the machine and the detectors would allow the collection of high-quality data amounting to ten times more integrated luminosity by around 2030. A strong scientific case for this High-Luminosity upgrade of the LHC (HL-LHC), which builds upon a machine and on detectors already validated by real operations, is already in place. Profiting from the tenfold increase in statistics and from improved detectors, ATLAS and CMS will have access to rare production modes and rare decay channels of the Higgs boson, will significantly improve the precision in the measurement of many of the Higgs couplings, will study its self-coupling via double Higgs production, and will test possible deviations from the Standard Model predictions in the scattering of longitudinal massive vector bosons. High-luminosity will also provide additional opportunities for the searches for new physics, and the proposed upgrades of the LHCb and ALICE experiments will push further the studies of flavour physics in the quark sector and of the quark-gluon plasma. In conclusion, the full exploitation of the LHC potential, including the high-luminosity upgrade of the machine and of the detectors, is identified as Europe's highest scientific priority.

CERN, today's world-leading laboratory at the high-energy frontier, is Europe's greatest asset in particle physics. Pushing further the high-energy frontier has been indispensable for tackling many of the most exciting questions in particle physics, and it is likely to remain so in the future. To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update. The process to prepare for future decision making on the next large project at CERN has to be started now, although the physics output of the 2015-2017 full-energy run of the LHC is essential for a decision. There are two most promising lines of development towards the new high-energy frontier after the LHC - proton-proton and electron-positron colliders. They both need focused design studies and vigorous accelerator R&D with adequate resources, in collaborations involving CERN and national institutes, universities and laboratories worldwide. The Compact Linear Collider (CLIC) is an electron-positron machine based on a novel two-beam acceleration technique, which could reach in stages a centre-of-mass energy up to 3 TeV, and for which a Conceptual Design Report exists. Possible proton-proton machines of higher energy than the LHC include HE-LHC, roughly doubling the design LHC centre-of-mass energy in the present tunnel, and V-LHC, aimed at reaching up to 100 TeV in a new circular 80km tunnel. Such a large tunnel would also allow to host a suggested circular electron-positron machine (TLEP) that could reach energies up to 350 GeV with high luminosity. In parallel with the required design studies for the above-mentioned projects, the crucial R&D activities for assessing their feasibility include those on high-gradient accelerating structures in the case of CLIC, and those on high-field magnets in the case of HE-LHC and V-LHC. Besides this focused R&D, Europe should also pursue accelerator R&D programmes aimed at a broader scientific community. In this regard, the TIARA project, which aims at developing a distributed Test Infrastructure and Accelerator Research Area in Europe, could play an important role.

There is a strong scientific case for an electron-positron collider that could initially study the Higgs properties with high precision, in a way complementary to the LHC, and be later upgraded to higher energy. Already at energies around 250 GeV, such a machine could perform precise and model-independent measurements of the Higgs branching ratios, with sensitivity to most decay modes at the percent level. At energies around 350 GeV, such a machine could perform precision tests of the top quark properties. At energies of 500 GeV and higher, such a machine could explore further Higgs properties, for example the coupling to the top quark, the self-coupling and the total width. It could also search for colour-neutral new particles, for example some dark matter candidates that may have escaped detection at the LHC. If the ILC were to be built in Japan with a substantial contribution from Japan, it would open a new window of opportunity in particle physics. European groups have already made several crucial contributions to the recently-completed Technical Design Report and there is a strong interest in participating in the ILC project. Until now, it is the Japanese high-energy physics community that has expressed unanimous support to host the ILC in Japan. However, much progress on the political side has been reported to the ESG meetings. Europe should be prepared for the case in which the Japanese government approaches Europe with a clear plan for hosting the ILC in Japan.

The recent discovery of a new type of neutrino oscillations makes a strong case for a long-baseline neutrino programme capable of determining the mass hierarchy, exploring a good fraction of the parameter space for CP violation in the neutrino sector and measuring more precisely the oscillation parameters. Measurements of the mixing angle θ_{13} by the reactor neutrino experiments, in particular Daya Bay and RENO, indicate that experiments with an accelerator neutrino beam produced by conventional method can make significant progress. Europe is at the forefront of some neutrino detector R&D particularly suited for the accelerator studies of neutrino oscillations. It would be important to reconstitute an activity in neutrino physics at CERN, to provide technical expertise, support and focus for Europe to play a leading role in the forthcoming experiments. The overall cost of a long baseline neutrino project, including detector, experimental area and beam line, would be substantial. Therefore, such an experiment must be realised in the global context, where accelerator-based long-baseline neutrino oscillation projects with similar goals have already been proposed in the US and in Japan.

Many other large-scale scientific activities with solid motivations have been proposed for the present Strategy. But, they were not included among the top four priorities, on the bases of the state of particle physics at the time of this Strategy update, the balance between the required human and financial resources and the expected availabilities, the time scale and compatibility with other projects and technological maturity. Prominent examples are the LHeC, LEP3, photon-photon colliders, and muon colliders. The LHeC is a large electron-proton (-ion) collider, obtainable by adding an electron beam to the LHC, for which a Conceptual Design Report exists. It would go much beyond the previous machine for high-energy lepton-hadron scattering, HERA, both in kinematic reach and in luminosity. It would be mostly relevant for studies of the strong interaction. LHeC-related technological studies of the possibility energy recovery from the spent electron beam could be useful also for other future accelerators. LEP3, for which only a preliminary study exists so far, stands for a circular electron-positron collider in the existing LEP/LHC tunnel, with centre-of-mass energy roughly 15% higher than the maximum one reached by LEP, but with potentially much higher luminosity. It could perform high-precision studies of Higgs boson and weak boson properties that do not require higher energies, with the existing ATLAS and CMS detectors. An advantage would be the cost saving from the use of existing tunnel and detectors and the main disadvantage would be the impossibility of upgrading the machine to higher energies. Alternative Higgs-factories proposed for the present Strategy are photon-photon colliders, built from high-energy electron beams and very intense laser beams, and muon colliders, with possible synergies with a neutrino factory and long-term prospects towards multi-TeV colliders, but both concepts are still very far from technological maturity.

Other scientific activities essential to the particle physics programme

> g) Theory is a strong driver of particle physics and provides essential input to experiments, witness the major role played by theory in the recent discovery of the Higgs boson, from the foundations of the Standard Model to detailed calculations guiding the experimental searches. *Europe should support a diverse, vibrant theoretical physics programme, ranging from abstract to applied topics, in close collaboration with experiments and extending to neighbouring fields such as astroparticle physics and cosmology. Such support should extend also to high-performance computing and software development.*

The community of theoretical particle physicists is global and well connected. An important hub for theoretical particle physics in Europe is the Theory Unit at the CERN Laboratory, which, besides conducting forefront research, provides a meeting point for the worldwide community, and a natural interaction point between theorists and experimentalists. In parallel to their research activity, theorists also play a crucial role in the training of students, both theoretical and experimental.

Calculation-intensive areas such as precision phenomenology at colliders, lattice field theory or the development of Monte-Carlo event generators and other software tools require long time scales to give results. This might be a handicap for the career of theorists involved in these challenging activities, especially in the early stages of their research. It would be important to find suitable frameworks (e.g., longer post-doctoral appointments) to evaluate and fund these activities, and to ensure adequate career prospects for the researchers involved.

For what concerns EU funding, individual grant schemes such as ERC grants and Marie-Curie Fellowships are well suited to the needs of the theory community. However, some other EU funding schemes, for example the Initial Training Networks, with their emphasis on the training of pre-doctoral researchers and the requirement of private-sector involvement, or the large actions linked to EU "strategic" areas, are not particularly suited for particle theory. A more flexible format for the EU funding actions, allowing particle theory to compete on a level field with the other disciplines, would be highly desirable.

The shifts in the paradigms induced by the steady production of new results by the LHC experiments will require a higher investment in theory than before to prepare the input for future strategic decisions.

> h) Experiments studying quark flavour physics, investigating dipole moments, searching for charged-lepton flavour violation and performing other precision measurements at lower energies, such as those with neutrons, muons and antiprotons, may give access to higher energy scales than direct particle production or put fundamental symmetries to the test. They can be based in national laboratories, with a moderate cost and smaller collaborations. *Experiments in Europe with unique reach should be supported, as well as participation in experiments in other regions, especially Japan and the US.*

In the search for new physics, precision measurements are truly complementary to the direct search of new particles at the energy frontier. In the past, they made essential contributions to establishing the Standard Model. Studies of kaon and hyperon decays led to establishment not only the flavour mixing, but also the family structure and the existence of the third family in the quark sector, well before their confirmation by the discovery of new particles. Studies of b-hadrons have extended further this line of research. The two B-factory experiments, Babar in the US and Belle in Japan, showed that the Standard Model mechanism is largely responsible for the observed CP violation phenomena in particle physics. It also shows that the energy scale for the violation of flavour symmetry is well above those accessible by the high-energy frontier accelerators of the foreseeable future. More recently, the LHCb experiment at the LHC has started to restrict severely the allowed parameter spaces for various models of supersymmetry, and BES III at IHEP (China) is improving the statistics on charm hadrons. Most of the measurements by the LHCb experiment are still statistically limited and their precision will further improve during the coming data taking runs since the b-$\bar{b}$ cross-section is expected to be almost a factor of two larger at $\sqrt{s} = 14$ TeV compared to that at 7 TeV. The experiment has an upgrade plan to boost its statistics by an order of magnitude toward the end of this decade. At KEK in Japan, the KEKB storage rings and the Belle detector are undergoing their upgrade plan with an aim to collect almost two orders of magnitude more data than what was collected by the Belle experiment. The data taking is expected to start in 2016. In addition, various $K \to \pi\nu\bar{\nu}$ experiments are under preparation and being considered at CERN, FNAL (the US) and JPARC (Japan).

Neutrino mixing shows that the flavour quantum number is also not conserved in the lepton sector. However, the resulting flavour-number violation in the charged-lepton sector is far too small to be experimentally measurable. In most of new physics models, a large enhancement in the lepton flavour violation in the charged-lepton sector is expected, and the recent progress by the MEG experiment at PSI (Switzerland) searching for $\mu \rightarrow e\gamma$ decays starts to probe an interesting region of the parameter space of new physics models. In order to reach a sensitivity of 10^{-14} in the branching fraction, MEG is planning for a detector upgrade. Experiments to improve the current limit on other interesting processes with muons are being planned at FNAL, JPARC and PSI. In the long-term future, the Project-X at FNAL and the JPARC upgrade could significantly improve those measurements. In the τ lepton sector, many interesting τ lepton flavour violating processes have been studied by Babar, Belle and LHCb, and those measurements will be further improved by LHCb (and its upgrade) and Belle II at KEK. Combination of μ and τ studies can provide further constraints on possible new physics models.

The muon anomalous magnetic moment is currently measured with an experimental accuracy of 0.5 ppm and shows a 3.2σ deviation from the Standard Model calculations. This has generated large interest in interpreting the deviation as the contribution from physics beyond the Standard Model. Note that the theoretical contribution to the uncertainty is almost as large as that from experiment. A new experiment is being considered at FNAL and in a longer time scale also at JPARC.

Another important aspect of precision measurements is the test of fundamental symmetries. A permanent electric dipole moment (EDM) of a fundamental particle violates parity and time reversal symmetries. The Standard Model contribution is calculated to be far too small to be detected by any foreseeable future experiments. The searches for EDM range from neutrons, diamagnetic atoms, paramagnetic atoms, molecules, protons, deuterons, muons to electrons. For some new physics models, the current limits on EDM already put the energy threshold to be 10 to 100 TeV. The next generation of the experiments are being planned for the neutron EDM at ILL (France), PNPI (Russia), FRM-2 (Germany), PSI and few other places. For other particles, many more projects are being planned at various national laboratories and at university institutes.

Antimatter studies using in particular anti-protons produced at CERN are testing fundamental symmetries such as the equivalence principle or the existence of additional forces using anti-hydrogen atoms.

It is important to note that these activities are with a moderate cost and most of them are conducted at different national laboratories worldwide. Although the scale of the detectors is smaller than those for the general purpose detectors at LHC, they adopt the state-of-the-art technology and contribute significantly to the detector R&D effort. Those experiments are addressing the most fundamental questions and small groups can make a significant contribution. Continuous encouragement and support for competitive projects in this field are essential to maintain the diversity of the field.

i) The success of particle physics experiments, such as those required for the high-luminosity LHC, relies on innovative instrumentation, state-of-the-art infrastructures and large-scale data-intensive computing. *Detector R&D programmes should be supported strongly at CERN, national institutes, laboratories and universities. Infrastructure and engineering capabilities for the R&D programme and construction of large detectors, as well as infrastructures for data analysis, data preservation and distributed data-intensive computing should be maintained and further developed.*

A high level of engineering expertise, special technical skills, and elaborate and large-scale infrastructure for design, construction and operation of complex detector systems are required to conduct state-of-the-art particle physics experiments. The development of better and more sophisticated detectors is a key for the success of all future experiments. Progress in particle physics relied in the past on detector innovation and will continue so for future projects. Steps have to be undertaken to maintain the capability of innovative detector R&D at CERN, national institutes, laboratories and university institutes. With increasing complexity and cost for R&D on detectors and associated electronics, coordinated R&D becomes essential. Establishing R&D consortia and global technological platforms would be of invaluable help for optimising the financial and human resources. In addition, the development of novel detectors always necessitates the use of test beams and irradiation facilities. CERN and other national laboratories must provide these facilities including the technical support, the expertise and the excellent conditions of the infrastructure and beam instrumentation.

For the upgrade of existing and the construction of future large experiments, the roles of national laboratories and universities with large construction capabilities are absolutely crucial and these institutions should assure that the required expertise and infrastructures are preserved and maintained at the state-of-the-art level. Bringing-in and training of the next generation of young talented researchers able to cope with the future challenges in instrumentation and later taking responsibilities in leading the design and execution of large complex instruments is a must to maintain the vitality of particle physics and for the construction of future large projects. For this reason it is highly fruitful to encourage a plan that allows equal career prospects at the universities for both students and professors working on instrumentation and on physics analysis.

Particle physics relies also heavily on advances in computing in order to record and handle the large amount of data generated by modern experiments, to model the physics processes and to simulate the interactions of particles in the detectors. The rapid evolution of computing technology is again expected to create many new opportunities over the next decade. The Worldwide LHC Computing Grid (WLCG), run by a collaboration of institutes, national GRID consortia and CERN with computer centres across Europe and around the world, operates very successfully and enables the thousands of scientists on the LHC to produce physics results and new discoveries at remarkable speed. It is vital that the support for the operations teams and the WLCG centres be maintained at a level to ensure the full exploitation of the data produced by the LHC in the coming years. The HL-LHC will be the next big challenge. The expected increases in trigger rate, pile-up and detector complexity (number of channels) could increase the data rates, and the storage and CPU requirements by about a factor of 10 or more. The LHC community is beginning to review and explore new computing models as they make plans for the next decade. A broader HEP-wide forum is needed where strategic issues for computing for the next decade can be discussed and the common work coordinated. Many particle physics experiments have a lifecycle that is beyond the lifecycle of the computing technology used and as a consequence data preservation is a large concern. The study group for Data Preservation and long-term analysis in High Energy Physics (DPHEP) has taken the lead in this important area. The experimental collaborations in particle physics are aware of the need of data preservation and for open access to the data and are developing clear policies and plans.

> j) A range of important non-accelerator experiments take place at the overlap of particle and astroparticle physics, such as searches for proton decay, neutrinoless double beta decay and dark matter, and the study of high-energy cosmic-rays. These experiments address fundamental questions beyond the Standard Model of particle physics. The exchange of information between CERN and ApPEC has progressed since 2006. *In the coming years, CERN should seek a closer collaboration with ApPEC on detector R&D with a view to maintaining the communitys capability for unique projects in this field.*

Astroparticle physics deals with the study of particles originating in space. Those particles are used to address issues in astrophysics. On the one hand, those particles, and the phenomena they are revealing, can also bring information on the intimate structure of matter and the fundamental laws that govern their interactions. In this respect, these studies fully pertain to the field of particle physics. On the other hand, detection of cosmic rays such as high-energy particles or gamma-rays, neutrinos, or gravitational waves, are or will be opening up new observing windows in astronomy. This is clearly out of the scope of particle physics and of the present Strategy. However, astrophysical sightings of violent phenomena from the Big Bang to black holes, and in fact the whole universe history, i.e. cosmology, are laboratories to test the structure of the fundamental laws of particle physics and gravitation. In addition, non-accelerator particle physics experiments, such as searches for dark matter, proton decays and neutrinoless double beta decays, and studies of non-accelerator neutrinos, are also labeled as astroparticle physics in Europe. There are some physics issues addressed by both astroparticle and accelerator experiments: Measurements of the neutrino oscillation parameters and mass hierarchy, and the search for sterile neutrinos are a few of the examples.

For the Strategy update, four research domains have been identified - dark matter, proton decay, high-energy cosmic particles (neutrino, gamma-ray, charged particles) and neutrino physics - as relevant for particle physics. Astroparticle physics experiments and experiments at accelerators have a number of common tools such as detectors and theory support, where close collaborations can be formed between particle and astroparticle physics communities.

In Europe the astroparticle physics activities are coordinated by ApPEC (Astroparticle Physics European Consortium. ApPEC is in charge of the roadmap for Astroparticle Physics in Europe. The scientific enlargement of CERN is under discussion. In 2011, the proposal for a joint CERN-ApPEC Work-plan for the period until 2012 has been endorsed by CERN Council. ApPEC is represented in the CERN Council Strategy Session and CERN is represented in ApPEC. Several of the astroparticle physics experiments are now recognised experiments of the CERN Laboratory. These collaborations benefit from logistics support of CERN. The question can be asked whether this support should be enlarged. This can be easily the case for detector R&D and theory.

> k) A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

Nuclear physics corresponds to the study of matter self-organised by the strong interaction. Nuclear physics covers the study of the structure of atomic nuclei in terms of particles and the study of particles and of hot and dense matter and in terms of quarks and gluons. It addresses also the question of nuclear dynamics and nuclear decay through strong, electromagnetic and weak interactions. Nuclear physics is strongly linked with particle physics, both through the elementary interactions and, in particular, the strong interaction described by the Quantum Chromo Dynamics (QCD), which are part of the Standard Model, and through the experimental techniques, accelerators and detectors.

Through the heavy-ion programme at the LHC, not only with ALICE but also with CMS and ATLAS, CERN is performing experiments which are in many countries considered part of nuclear physics. This is also the case for research dealing with the content of nucleons in terms of partons (quarks and gluons). Moreover, the CERN Laboratory has developed over the years an ensemble of beams and experimental facilities which are vital for the field of nuclear physics.

In Europe, the Nuclear Physics activities are coordinated through NuPECC (Nuclear Physics European Coordination Committee). NuPECC is responsible for the forward-look of activities and the associated roadmap for Nuclear Physics in Europe.

Organisational issues

> l) Future major facilities in Europe and elsewhere require collaboration on a global scale. *CERN should be the framework within which to organise a global particle physics accelerator project in Europe, and should also be the leading European partner in global particle physics accelerator projects elsewhere. Possible additional contributions to such projects from CERNs Member and Associate Member States should be coordinated with CERN.*

It is a well-established practice in particle physics that experiments are conducted by a collaboration of institutes from all over the world and the cost of detector construction and operation is shared by all participants. On the other hand, accelerators used to be built and operated by a single national laboratory or CERN. With the increasing cost of energy-frontier machines, it has become more and more difficult for a single country or CERN to build such machines with their resources only. HERA and LHC are recent examples where outside institutes contributed to the construction of accelerators by providing parts, expertise, and manpower. This will become even more important for the future energy-frontier machines, where the cost and effort for the construction, and possibly the operation, require a collaboration of institutes on a global scale. After adopting the first Strategy in 2006, the Council in its March session in 2010 approved a set of statements as a framework for the European participation to accelerator projects to be constructed globally:

1. CERN is prepared to join partners in discussions about new governance structures for future global accelerator projects.
2. In particular, CERN is prepared to provide an institutional framework within which a "Project Governing Board" could direct a global accelerator project.
3. As a prototype implementation of such an institutional framework for a global accelerator project, CERN should explore a governance structure for future upgrades of the LHC.
4. CERN is willing to consider hosting a future global accelerator project, if it is deemed to be in the interest of the Organization and the global particle physics community.
5. In the case of a future global accelerator project hosted elsewhere, CERN is willing to coordinate broad European participation.

In view of the global aspect of particle physics addressed previously in this document, and, in particular, of the recent development in the ILC, the fifth statement should be elaborated further for the case where a future global scale accelerator would be build outside of Europe and CERN Member States and Associate States would like to contribute to its construction. In order to maximise the European impact on the project, it is essential that the European contributions are well coordinated and European countries speak coherently.

The European contribution could be through CERN as a special programme participated by some of the Member States or as a part of the base programme depending on the decision by the Council. In both cases, the Director- General as the Chief Executive Officer of the CERN Organization would have the mandate of the Council to be responsible for such contributions, in consultation with relevant partners. In addition, national laboratories may make a substantial contribution with resources provided by their own governments. For some cases, there could be direct contributions by the governments. For such cases, the CERN Laboratory could still play a role of a European convener and provide logistic support to facilitate in-kind contributions by the national laboratories. In this context, setting up a Consortium of European National Laboratories, including CERN Laboratory, appears to be a possible model and should be explored.

m) A Memorandum of Understanding has been signed by CERN and the European Commission, and various cooperative activities are under way. Communication with the European Strategy Forum on Research Infrastructures (ESFRI) has led to agreement on the permanent involvement of CERN in the relevant ESFRI Strategy Working Group. The particle physics community has been actively involved in European Union framework programmes. *CERN and the particle physics community should strengthen their relations with the European Commission in order to be further integrated in the development of the European Research Area and to benefit from future instruments in Horizon 2020 and the Structural Funds.*

Besides CERN, with its Council and Committees, there are other European organisations active in Particle Physics (ECFA, the European Committee for Future Accelerators; EPS-HEPP, the High Energy and Particle Physics Division of the European Physical Society; ESGARD, the European Steering Group for Accelerator R&D), in neighbouring fields (ESO, the European Southern Observatory; ESA, the European Space Agency; ApPEC, the Astroparticle Physics European Consortium; NuPECC, the Nuclear Physics European Collaboration Committee) and in a broader context (chiefly the European Union, with the variety of its Programmes, but also EIROforum, the European Intergovernmental Research Organizations forum). There are also additional organisations at the global level, both in Particle Physics (the C11 Commission of IUPAP, the International Union of Pure and Applied Physics; ICFA, the International Committee for Future Accelerators; FALC, the Funding Agencies for Large Colliders), in neighbouring fields (APIF, the Astroparticle Physics International Forum) and in a broader context (the Global Science Forum of the OECD, the Organization for Economic Co-operation and Development).

The relations between CERN and the other Particle Physics organisations in Europe are all well established, with properly-defined roles understood by the community. The relations with organisations in neighbouring fields are still in evolution, and the possibilities of cooperation, both on general policy issues and on thematic cooperation areas, could be exploited further, with improved coordination. The last comment extends to the organisations at the global level.

Important progress has been made in the relations between CERN and the European Union. The lasting concern on how to incorporate the strategic projects of European Particle Physics into the ESFRI Roadmap has been addressed by the recent agreement on the permanent involvement of CERN in the relevant ESFRI Strategy Working Group. It would be important to open further communication and consultation channels with the European Union, with a more direct involvement of all the organisations representing the European Particle Physics community, to better align the strategies and to ensure the flexibility required to make the most efficient use of European funds.

Wider impact of particle physics

n) Sharing the excitement of scientific discoveries with the public is part of our duty as researchers. Many groups work enthusiastically in public engagement. They are assisted by a network of communication professionals (EPPCN) and an international outreach group (IPPOG). For example, they helped attract tremendous public attention and interest around the world at the start of the LHC and the discovery of the Higgs boson. *Outreach and communication in particle physics should receive adequate funding and be recognised as a central component of the scientific activity. EPPCN and IPPOG should both report regularly to the Council.*

The progress and the discoveries in particle physics, especially at CERN, have attracted worldwide attention and increased public awareness for the field of particle physics. CERN has moved into the focus of the public and has become a globally-known science brand. Due to this very positive evolution professional communication is indispensable and public outreach has become a golden opportunity to reach a large number of interested citizens. Both communication of results and public engagement should be seen as a duty of the scientists. The recommendation of the Strategy process in 2006 to establish a European Particle Physics Communication Network (EPPCN) has been followed and a network of communication officers from almost all CERN Member States has been formed. It is coordinated by CERN and reports to the European Strategy Session of Council. EPPCN members are typically communication officers in Research Councils and Ministries who know and understand their countrys key stakeholders and science commentators. This network has efficiently communicated the progress in particle physics, with highlights such as the start of the LHC and the discovery of the new Boson in 2012.

EPPCN works very closely with the International Particle Physics Outreach Group (IPPOG), which consists of physicists actively engaged in education and outreach, and the InterActions network of communications officers from major labs and agencies around the world. These scientists take an active role, by authentically conveying the fascination of fundamental research and thereby especially reaching out to young people. A large variety of outreach and education efforts are already carried out with great success in Europe as well on the national and international level, such as lectures, site tours, science shows, and exhibitions. A major success of IPPOG are the international Masterclasses "hands on particle physics", where more than 160 institutes from 33 countries have taken part in offering annually over 8000 young students measurements with real data from CERN and connecting them, at the end of the day, in an international video conference. To continue the success of IPPOG and to develop new projects, a sustainable funding scheme for this group is required.

Communication and public engagement needs to be further strengthened and supported. Ph.D. students and young scientists should be encouraged to take part in these activities, assisted by a professional training to develop the skills needed to interact with the public and the journalists. Finally, involvement in outreach activities should be acknowledged and officially recognised during the career progression.

o) Knowledge and technology developed for particle physics research have made a lasting impact on society. These technologies are also being advanced by others leading to mutual benefits. Knowledge and technology transfer is strongly promoted in most countries. The HEPTech network has been created to coordinate and promote this activity, and to provide benefit to the European industries. *HEPTech should pursue and amplify its efforts and continue reporting regularly to the Council.*

Particle physics addresses basic science issues on the microscopic structure of the Universe, which are in general very far from immediate applications. However, to address these issues at the frontier of what is experimentally accessible, the particle physics community is forced to invent and construct instruments: accelerators, detectors and information technology, at the cutting edge of technologies. These technologies invented and brought by the Particle Physics community to a high level of technical reediness have the potential to generate important spin-offs for other research communities and the society in general, as already successfully demonstrated in the past in several domains (from the World Wide Web to the development of innovative diagnostic and therapeutic medical facilities). This transfer broadens the user base, the R&D and construction actors also speed up the development and the maturity of technologies needed for particle physics experiments leading to mutual benefit.

Initiating in a coordinated manner knowledge and technology transfer was one recommendation of the first Strategy. This recommendation has been implemented, in particular through the creation of a network, called HEPTech. This action needs now to be amplified and Working Group 4 of the ESG has produced a report with implementation proposals. A regular reporting of HEPTech at the Council sessions is a way to closely monitor the efficiency and the amplification of this activity.

p) Particle physics research requires a wide range of skills and knowledge. Many young physicists, engineers and teachers are trained at CERN, in national laboratories and universities. They subsequently transfer their expertise to society and industry. Education and training in key technologies are also crucial for the needs of the field. *CERN, together with national funding agencies, institutes, laboratories and universities, should continue supporting and further develop coordinated programmes for education and training.*

Human capital is the key for the future of the field and for an efficient dissemination of knowledge and knowhow to the society. Unfortunately, most countries are now facing a difficulty to motivate and train new generations of scientists and engineers. CERN and national particle physics institutions, because of their global nature and the level of the scientific and technological challenges, have been a strong education and training ground and strong attractors toward science and technologies for the new generation. They should continue to attract, educate and train young students at local, national and international levels, and provide initial working experience for young engineers, who will then propagate the knowledge and technology to the outside world. However, room for improvement and amplification of these education and training actions exists and this key issue deserves to be addressed at the Council level.

Concluding recommendations

> q) This is the first update of the European Strategy for Particle Physics. It was prepared by the European Strategy Group with the participation of representatives of the Candidate for Accession to Membership, Associate Member States, the Observer States and of other organisations. Such periodic updates at intervals of about five years are essential. *Updates should continue to be undertaken according to the principles applied on the present occasion. The organisational framework for the Council Sessions dealing with European Strategy matters and the mechanism for implementation and follow-up of the Strategy should be revisited in the light of the experience gained since 2006.*

Under Article II of its Convention, CERNs mission is to provide for international collaboration in the domain of fundamental research in particle physics, and to execute this task through two activities: The construction and operation of accelerator-based laboratories and the organisation and sponsoring of international cooperation in particle physics in and outside the laboratories. As an intergovernmental Organization, CERN is governed by two bodies: The Council, supreme decision-making body, and the Director-General, Chief Executive Officer. In its capacity as supreme decision-making body, the Council has the authority and responsibility of deciding on all aspects of CERNs mission, i.e. the construction and operation of the laboratories or the organisation and sponsoring of international cooperation in the field of particle physics.

After adopting the Strategy in June 2006, the Council introduced several changes to the CERN Organization to cope with the role as coordinator of European particle physics. A special procedural framework in which Strategy matters were to be addressed, i.e. the "European Strategy Session of Council", was introduced. This Session, organised separately from regular Council sessions, has a well-defined remit, a separate agenda, additional ex-officio attendees compared to the ordinary Council session. It is chaired by the President of the Council with the Scientific Secretary, who is elected by the Council, acting as the secretary. The remit of the European Strategy Session is to update the Strategy and follow up its implementation by

- enhancing the networking and coordination between all the actors in European particle physics by providing a forum for dialogue and interaction between the representatives of the Member States,
- making recommendations to the Member States with a view to harmonising the national and supra-national programmes in the context of the implementation of the Strategy, and
- providing, in accordance with Statement 12 of the Strategy, the framework for Europe to engage with the other regions of the world with a view to optimising particle physics output through the best shared use of resources, while at the same time maintaining European capabilities.

It is also foreseen that infrastructure projects with a global or European dimension are submitted for consideration by the Council at its European Strategy Session and that the Council will recognise an infrastructure project as being relevant to the Strategy following a proposal by the Scientific Secretary. A special secretariat (Scientific Secretariat chaired by the Scientific Secretary) was set up to assist the Council for implementation.

After gaining experience in defining and implementing the Strategy, the current organisational structure of and procedures governing the "European Strategy Session of the Council", as laid down above, should now be revisited. The remit of the European Strategy Session requires that all Strategy matters be dealt by this specific Session and under its specific procedural requirements. On the other hand, past experience shows that there is often a few Strategy items which require urgent discussion and decision by the Council through-out the year. Since holding a separate Strategy Session required additional large administrative effort, such items were treated during the regular session of the Council on several occasions, which was in principle against the applicable rule. As it has become clear that the coordination of European particle physics should be one of the core missions of CERN, the Council may consider making the Strategy matters formally included in the base activities of the CERN Organization. Issues related to the Strategy would then become agenda items of the regular session of the Council where the Director-General acts as the Secretary, however with a different list of attendants. In a similar way, implementation of the Strategy could also be seen as one of the Council decisions executed by the Director-General. To this end, the Scientific Secretary and Scientific Secretariat may not be needed, since the Strategy implementation would be reported to the Council by the Director-General and the Scientific Policy Committee would be the advisory body to the Council also for the Strategy matter.

On the other hand, the Strategy covers all the particle physics activities in Europe, including those taking place in the national laboratories. For the definition phase of the Strategy, a body specially appointed by the Council and independent from the executive branch of the CERN Organization, is therefore essential. The preparation of a draft for the periodic update of the Strategy should continue to be undertaken in accordance with the principles and procedures laid down in documents CERN/2732/Rev. and CERN/2779. For each Strategy update exercise, the Council should appoint a dedicated Chair of the ESG who will be in charge of producing the draft. The ESG should be assisted by a Preparatory Group consisting of worldwide-leading scientists with a responsibility to gather the community view on the Strategy. The composition of the ESG should be carefully examined to keep a balance between the efficient running of the group and the appropriate representation of relevant communities.