Discussion of the
Draft Strategy Document Initiatives

From the remit to the Strategy Group:
At a meeting in Zeuthen-Berlin from 2-6 May 2006, the Strategy Group shall produce a Draft Strategy Document (DSD) addressing the main lines of Particle Physics in Europe, …

The DSD shall comprise a series of ordered and concise statements, of 1-2 pages, followed by presentations and discussions of the initiatives, not exceeding 25 pages.

The discussion of the initiatives in the Draft Strategy Document that follows is based upon the conclusions of the Zeuthen meeting working groups, and the presentations in the Briefing Book prepared for the Strategy Group.

General issues

1 The foundations of particle physics in Europe

> European particle physics is founded on strong national institutes, universities and laboratories and the CERN Organisation; *Europe should maintain and strengthen its central position in particle physics.*

European particle physics has played a crucial role in establishing the foundations of our current understanding of the ultimate structure of matter and of its interactions, with cornerstone discoveries such as the neutral currents, the gluon, and the W and Z gauge bosons, and with seminal theoretical work. This success is based on the fruitful collaboration between strong national institutes, universities and laboratories, and the CERN Organization. This combination of a world-leading international laboratory and a “constellation” of national institutions provides a fertile environment in which the collective effect of the large-scale common projects maximises the European impact while the individual programmes of the institutions (often themselves international) foster diversity and creativity. With the ISR, SPS, PETRA, the proton-antiproton collider, LEP, HERA, and now the Large Hadron Collider (LHC), Europe has hosted a series of energy-frontier machines, and established Europe as a leader in the field. It is fundamental that, as the scale of the frontier machines increases and hence their number worldwide decreases, Europe maintains and strengthens its central position in particle physics.

2 The changing global environment for particle physics

> Increased globalisation, concentration and scale of particle physics make a well co-ordinated strategy in Europe paramount; *this strategy will be defined and updated by CERN Council as outlined below.*

Particle physics is now confronted with new challenges. The machines operating or under construction (HERA, the Tevatron, the *B*-factories, the LHC…) already need global collaborations for the design, construction, and operation of their detectors, and there is increasing global collaboration on the design and construction of the accelerators. Uncovering the fundamental physics that so far lies beyond the current understanding is likely to need new facilities (the ILC, neutrino sources…) and upgrades to existing ones (the LHC…) that require global collaboration. This global collaboration is needed not only for financial reasons, but also because the challenges presented by these new facilities need to harness the global intellectual resources. If Europe as a whole is to contribute to, and benefit from, this global enterprise, it is paramount that Europe has a clearly articulated and well-coordinated strategy. Such a strategy needs to be defined, and, once defined, must be updated as the programme evolves. The CERN Council has, through its Convention, the necessary authority to assume this role.

Scientific Activities

3 The LHC

The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field*; the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.* A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; *to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.*

3.1 The physics programme

Several of the existing puzzles in particle physics point to the TeV scale as the arena for new phenomena, making it compelling that new physics is present in the energy range explored for the first time by the LHC. The physics potential of the LHC is therefore immense, and holds the promise of fundamental new discoveries, in particular new elementary particles and interactions in the mass region from 0.1 to a few TeV. In addition to the detection of the Higgs boson, which would complete the spectrum of the Standard Model (SM), the LHC has the potential to discover particles predicted by supersymmetry, new forces mediated by new gauge bosons, to probe processes associated with the existence of new dimensions of space, and perhaps to reveal completely unexpected phenomena.

As a complement to the direct searches for new physics, a rich and very important precision measurements programme will be performed at the LHC. Electroweak parameters (vector boson self-couplings, top and W mass) may provide hints of new physics (composite structures, new vector bosons, new couplings…). The LHC will also allow very significant measurements of top quark properties, including searches for flavour changing neutral current (FCNC) decays with a branching ratio sensitivity of up to 10^{-5}. In addition, rare B decays in purely leptonic channels, CP violation in B_d and in B_s mesons, B_s mixing and measurements of $b \rightarrow s$ transitions, form a very important component of the physics programme.

An upgrade of the LHC luminosity to 10^{35} $cm^{-2}s^{-1}$ would maximize its unique physics potential by allowing an extension of its discovery range and more accurate studies of the observed new phenomena. It would enable a very important improvement in the studies of the Higgs boson properties and couplings, or to examine the structure of strong electroweak boson interactions via precision measurement of $V_L V_L$ cross sections unattainable at the nominal luminosity. The luminosity upgrade would also increase the mass reach for the observation of new heavy particles, like supersymmetric states or new gauge bosons, by about 30%.

3.2 The experimental needs

At the start-up of the LHC both ATLAS and CMS will have detectors that are adequate for initial running, but require completion in the period leading up to nominal LHC luminosity. 'Staging' has mainly, but not only, been achieved by reducing the trigger and DAQ systems; the upgrade to nominal performance is fundamental, and will require further investment in the period 2008-2010.

Computing for the LHC still needs, in the same period, additional funding for the Tier-1 centres and the CERN-based Analysis Facility in order to reach full capacity.

3.3 The LHC accelerator complex, its consolidation and upgrade

Efficient running of the LHC accelerator complex is essential to optimize the integrated luminosity and therefore maximize the discovery potential. This requires the consolidation of the weakest elements in the injector chain, notably the PS and SPS main magnets. This is partly foreseen in the CERN budget plan for the coming years, but the more drastic and comprehensive approach that is needed will require additional resources.

In this context, but also with a view to a future LHC luminosity upgrade, it is important to replace the Linac at the beginning of the injection chain (LINAC2), by a higher energy Linac (LINAC4) to remove a bottleneck in transferring the beam into the booster (PSB). The replacement of the PS (built in 1959) by a new synchrotron reaching 50 GeV, which could be conventional or be built with fast cycling superconducting magnets (requiring R&D), would bring considerable additional benefits.

To reach the luminosity of 10^{35} $cm^{-2}s^{-1}$, modifications to the LHC itself will be necessary, most notably new inner triplets and RF system. To make this possible, it is fundamental that the R&D into next-generation higher-field magnets is pursued as a matter of urgency.

3.4 The upgrade of the experiments

Operation at such high luminosity requires upgrades of the experiments, which requires a programme of R&D, in particular on tracking devices, readout electronics and triggering/DAQ systems. The collaborations at large have the background and expertise to develop many of the new detector elements for the SLHC. The central CERN effort and resources should be channeled through the Technical Coordination of the experiments for such upgrades to be implemented safely and efficiently, for co-ordinated optimisation of the detector/accelerator interfaces, and for common electronics developments.

The way forward for the LHC and detector upgrades will be based on the first LHC results, the experience from accelerator and detector operation, and the R&D and preparatory steps mentioned above, and can be defined around 2010, for completion by 2015. Exploitation of the LHC programme, including a luminosity upgrade as outlined above, would then continue until 2020-2025.

4 Advanced accelerator R&D

> In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high-performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

It is very plausible that the LHC results will indicate the necessity for further extending the energy frontier. A multi-TeV e^+e^- collider is widely believed to be the most versatile and powerful instrument to do so. However, in some scenarios a high-energy hadron machine might be a better choice. In addition, the pursuit of the neutrino programme beyond the presently active experiments will almost certainly require a very-high-intensity neutrino-beam facility.

While the results from the LHC will provide the main guidelines for the future, the options above are not yet developed or technologically mature, and directed accelerator

R&D over the next 4-6 years is of paramount importance for the future of European particle physics.

In the scenario where an LHC luminosity upgrade is undertaken there would be no place in Europe for major new accelerator construction activities before 2015 at the earliest. The second key element of a strategy for high energy physics in Europe is therefore to embark now on directed accelerator R&D that will allow Europe to define its next frontier accelerator project as soon as possible after 2010, aiming for completion around 2025. These initiatives require a strong collaboration between CERN and the European national laboratories. Examples of existing projects are CARE, EUROTeV, EURISOL, and CTF3. It is natural that CERN plays a central role in such collaborations.

The most urgent R&D fields to pursue are reviewed in the following.

4.1 The Compact Linear Collider (CLIC)

The physics case for a multi-TeV e^+e^- collider such as CLIC is very strong. CLIC will extend the reach for heavy Higgs states significantly. It would add new information on rare Higgs decays, such as the decay $H\rightarrow\mu\mu$ for m_H in the range 120-140 GeV and the decay $H\rightarrow bb$ for m_H between 180 and 240 GeV. In the mass range 120-240 GeV, double Higgs production at 3 TeV would allow the measurement of its trilinear coupling to a precision of approximately 10%. The large Higgs samples will also be instrumental for increasing the precision on the ttH coupling, measurements of possible CP phases, and other Higgs physics.

The high energy of CLIC will also be instrumental in the search for heavy states of new physics. At 3 TeV, relatively heavy sparticles, in particular squarks and the heavier charginos and neutralinos, will be accessible and the sensitivity to new contact interactions will be increased.

The novel and challenging technology required to reach multi-TeV e^+e^- collision energies is being developed in the framework of the international CLIC Test Facility 3 (CTF3) collaboration and EUROTeV. CLIC's key feature is the generation of high-frequency, high-power RF through a 'drive beam', leading to acceleration gradients of 150 MeV/m. The CTF3 collaboration aims to demonstrate the feasibility of all key CLIC-technology related issues by 2010.

Successfully demonstrating the CLIC technology opens the road for building a very versatile and powerful e^+e^- machine in Europe after the LHC, capable of addressing physics in the multi-TeV energy range in a unique way.

4.2 A very-high-energy proton-proton collider

The physics case for an energy-doubled LHC (DLHC) is less well studied than that of the SLHC and also requires detailed knowledge from the first exploration of the TeV scale. The mass reach of a 28 TeV proton-proton machine is up to 10-11 TeV for single-particle production. Supersymmetric particles could be discovered up to 4.5-5 TeV. A possible scale of quark compositeness could be probed up to 85 TeV.

The DLHC requires the development of a new generation of high-field magnets with twice the bending power of the present LHC dipoles. Related R&D is under way for the LHC luminosity upgrade programme, for focusing the beams just before the interaction point.

The injector studies needed for the SLHC also have relevance for the DLHC, particularly the option of injecting at 1 TeV from a new SPS.

While some work can be done before 2010 in the framework of the SLHC, the DLHC will require much more R&D beyond 2010. It is therefore important that there is a better understanding of the feasibility of the DLHC by then.

4.3 Very-high-intensity neutrino beams

The discovery of neutrino oscillations has revealed new physics that requires a modification and more likely a fundamental extension of the SM. Results from a variety of ongoing and planned experiments will allow more precise planning of future projects in this field, but it is very likely that physics will dictate the necessity of at least one major new neutrino project, as discussed in more detail below.

Various options for a future high-intensity neutrino facility have been investigated and are now at the level that fully fledged design studies are needed. In this respect, and specifically for CERN, a high-power (4 MW) linear proton accelerator (for example the SPL, using superconducting RF acceleration following LINAC4) would add unique capability to the proton accelerator complex. Also the possibility of a beta-beam (production of neutrinos through the beta decay of radioactive ions circulating in a high-energy storage ring) poses complex accelerator challenges that need to be studied. The neutrino studies in general should be addressed in the context of an International Design Study, in which CERN should play an important role within a strong collaboration of national laboratories in Europe.

5 The International Linear Collider (ILC)

> It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

5.1 The physics programme

The ILC offers a compelling and comprehensive physics programme of discoveries and precision measurements at the TeV scale and beyond, as has been shown in great detail through worldwide studies.

While the discovery of new particles often requires access to the highest possible energies, disentangling the underlying structure of which they are a manifestation calls for measurements with the highest possible precision. A 500 GeV to 1 TeV linear collider is therefore a fundamental tool for precision measurements. It will permit a detailed investigation of new physics beyond the SM and constrain many proposed theoretical models. The high-precision information obtainable at the ILC will be crucial for identifying the nature of new physics, and in this way new fundamental laws of nature can be discovered. For example, the Higgs couplings will be measured to ~1% level, a crucial step in understanding the Higgs mechanism itself and its realisation in different models, e.g. SUSY. Furthermore, the mass and properties of the lightest supersymmetric particle, a potential Dark Matter candidate, can be determined with high accuracy.

Electron-positron colliders also provide the best environment for precision measurements of the electroweak parameters and top quark properties, to look for small deviations from the SM and therefore for new physics. For such measurements, luminosity is often more important than energy. Indirect measurements at the ILC, for example, are sensitive to new bosons up to 10 TeV. The top-quark mass precision will reach 0.1 GeV, a factor of 10 better than the expected precision at the LHC. Together with the knowledge of M_w, this will allow the calculation of the Higgs mass, within the SM framework, to a precision comparable to the experimental one, providing a very important check of the overall consistency. The above measurements should be complemented by the Giga-Z option (running at the Z-boson pole with high luminosity), which would provide 10^{-5} precision on the weak mixing angle. The LHC and ILC are also sensitive to different gauge boson scattering channels, yielding complementary information. It has been clearly demonstrated that the results from the ILC will lead to definite conclusions about many features of physics at the TeV scale. The physics programmes of the ILC and LHC are highly complementary, as demonstrated and documented by the studies performed in many workshops.

Thus, an electron-positron collider with the appropriate energy reach is of fundamental scientific importance.

5.2 The Global Design Effort (GDE)

The design of the ILC is being addressed by a worldwide collaboration, the GDE, whose mission is to produce a design for the ILC that includes a detailed design concept, performance assessment, reliable international costing, an industrialization plan, siting analysis, as well as detector concepts and scope. The baseline design of the ILC foresees a first phase of operation with a tuneable energy of up to about 500 GeV and polarized beams. Options include the GigaZ, and running in the photon-photon, electron-photon and electron-electron collider modes. The physics case of the ILC with centre-of-mass energy of 400-500 GeV rests on high-precision measurements of the properties of the top quark at the top threshold, the unique capability of performing a comprehensive programme of precision measurements in the Higgs sector, which will be indispensable to reveal the nature of possible candidates of Higgs models, the good prospects for observing the light states of various kinds of new physics in direct searches, and the sensitivity to effects of new physics at much higher scales by means of high-precision measurements. The baseline configuration furthermore foresees the possibility of an upgrade of the ILC to about 1 TeV. The final choice of the energy and further possible machine and detector upgrades will depend on the results obtained at the LHC and the first phase of the ILC.

5.3 The European participation

The European participation in accelerator and detector R&D for the ILC and preparations for its design is very strong, for example through participation in the GDE and through the EuroTeV project. Given the resource situation in Europe is it also clear that decisive moves towards realisation and hosting the machine can only come from regions outside Europe in the short term. The participation in the decision and construction phase has clearly strategic and resource implications for European particle physics, therefore the Strategy Group has made two statements that concern the ILC. One is specifically that the ILC work in Europe must continue and the situation for the ILC must be assessed around 2010 taking into account all available information; and secondly that Council start to prepare a framework for discussion with global partners about future global projects (statement 12).

Europe should vigorously contribute to all stages of this fundamental, global project and consider the possibility to host this facility. CERN should take a significant role in the development of the ILC, independent of its site.

One of the contributions to the Strategy Group, included in Briefing Book 2, suggests that a proposal is made to the 7th framework programme for a supra-conducting RF facility based at CERN, to implement the European participation to the GDE and to preserve European expertise and leadership in this key area.

6 The neutrino programme

> Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; *Council will play an active role in promoting a coordinated European participation in a global neutrino programme.*

The discovery that neutrinos have mass is arguably the most important discovery in particle physics in the last 10 years, and constitutes the first clear-cut evidence for physics beyond the SM. It is suspected that the small neutrino mass stems from phenomena occurring at a very high energy scale. The physics case for the development of neutrino physics is independent of the arguments for experimentation at the high-energy frontier, and the information gathered on this research front cannot be collected otherwise. The physics questions that are addressed offer the potential for further fundamental discoveries, such as a Majorana neutrino mass, and/or leptonic CP violation, which, via leptogenesis, is today a serious candidate to explain the baryon asymmetry of the Universe.

The neutrino-oscillation community in Europe is very active and growing. Its members are involved in analysing or preparing current experiments (HARP, K2K, MINOS, OPERA), and in the preparation of experiments for the near future (Double-Chooz, T2K, perhaps NOνA). The long-term goals of the neutrino programme are the discovery of leptonic CP violation, precise measurements of the mixing angles and mass differences, and detailed tests of the mixing pattern. These are beyond the reach of the present or planned set of experiments; hence a major new facility will be necessary.

Several possibilities are being discussed. The two leading candidates are: i) the combination of a beta-beam and a conventional high intensity superbeam, aiming neutrino beams in the energy range of ~1 GeV or below at a megaton-class detector; ii) a neutrino factory based on a muon storage ring aiming neutrino beams of 20-50 GeV at magnetized detectors. Both possibilities are being developed at the conceptual level.

Each facility is a (large) regional or global project (estimated hardware cost 1-2 G€) requiring several years of technical R&D and design study, with an earliest decision date around 2010-2012 and completion date around 2020. Both facilities offer several other scientific opportunities, addressing topics of possible fundamental importance. The megaton-class detectors would greatly improve the sensitivity of searches for proton decay, and allow more accurate analyses of atmospheric and astrophysical neutrinos; the high-intensity proton sources would provide unprecedented statistics of muons and kaons permitting new studies and rare-decay searches, and would enable frontier investigations of nuclear structure. The neutrino factory, furthermore, is the first step towards muon colliders.

The choice of facility and the definition of its parameters are somewhat dependent on the value of the as yet unknown neutrino-mixing angle θ_{13}. By 2012, the knowledge about this parameter should be sufficient to allow a definite proposal for the facility.

The community is self-organizing at an inter-regional level in the study of the next-generation facilities, and for the R&D leading to them, both on the accelerator side

(MICE at RAL, MERIT at CERN, the beta-beam study in the context of EURISOL) and on the detectors (liquid-argon TPC, water Cherenkov and photosensors).

It is the view of the neutrino community that progress in the field will follow from the following actions:

1. Provision of strong support to enable the present and near-future programmes to be successful; the Double-Chooz experiment should be strongly supported and the involvement of European particle physicists in the neutrino physics programme abroad (such as T2K or perhaps NOνA) should be supported in a way that would assure a viable and significant contribution.
2. Preparations for Europe to host a major neutrino facility for the precision era, or to play a major role in the preparation and construction of this facility should it be located elsewhere; this would be best achieved if CERN played a major, perhaps leading, role in the upcoming accelerator-design study and detector R&D, in close collaboration with European laboratories and within an international collaboration.

European groups are working together on R&D and general conceptual plans exist for such future facilities. CERN should continue to foster the required environment for a strong and well-coordinated neutrino physics community in Europe. In this spirit, Europe should be ready to host or to participate with strong visibility to the realisation and exploitation of a very important global future neutrino facility.

In order to provide adequate funding and oversight to these efforts, a coordinated European programme under the auspices of the CERN Council is highly desirable.

7 Non-accelerator physics & the interface to the cosmos

> A range of very important non-accelerator experiments take place at the overlap between particle and astroparticle physics exploring otherwise inaccessible phenomena; *Council will seek to work with ApPEC to develop a coordinated strategy in these areas of mutual interest*.

A number of crucial particle physics issues are common to astrophysics and cosmology, and must be addressed by observation and/or experiments that do not use accelerator facilities; many use the Universe as a particle source. One may distinguish between themes especially relevant to astrophysics and/or cosmology, and those relating more directly to particle physics. However there is a great deal of overlap not only between these two themes, but also between the scientific communities involved and the experimental techniques used.

Nearly all of these lines of investigations are addressed by ApPEC, which is close to completing a comprehensive roadmap of projects covering the next decade. The Strategy Group recognizes the important role of ApPEC in coordinating and prioritizing these investigations.

The areas of more direct interest to astrophysics and cosmology include work along the following lines:

- Very-high-energy particles from the Universe detected with new types of observatories and telescopes. These include facilities to detect cosmic rays, neutrinos and gamma-rays over a broad spectrum extending to the highest observable energies;
- low-energy neutrinos from supernovae, the sun and the earth;

- gravitational waves from stellar collapse, spiraling binaries, etc.;
- axions from the Sun or the early Universe.

Because of the important and fascinating particle physics implications of this research and the involvement of many particle physicists from the accelerator-based community, many of these are CERN-recognized experiments. It is expected that CERN will continue to have a role in the coordination and logistics of these activities.

Four areas of primary importance to particle physics require strategic planning:

- **Proton lifetime:**

  The observation of proton decay would be a strong indication of the existence of particles at the $\geq 10^{16}$ GeV mass scale, consistent with the extrapolations of coupling constant strengths from LEP. In view of the cost of a proton-decay facility it is important to site it so that it could also be used as a far detector for a neutrino beam.

- **Nature of neutrinos:**

  The observation of neutrinoless double-beta decay would establish the neutrino as a Majorana particle, prove lepton-number violation and indicate the existence of a very large mass scale. Measurements with different isotopes would be required.

- **Dark matter:**

  Dedicated underground dark-matter searches will probe weakly-interacting massive particle (WIMP) cross sections at the level of 10^{-10}-10^{-11} pb over the next decade, thus probing a large part of the presently allowed supersymmetric parameter space. The parallel discovery of supersymmetric particles at the LHC would provide a likely candidate for Dark Matter, and the consistency with the results emerging from the direct detection of WIMPs would establish beyond reasonable doubt the nature of a major component of the Universe.

- **Dark energy:**

  Dark energy is one of the most astounding discoveries of the last decade. Its implications for particle physics are profound. Europe, including CERN, ESA and ESO, needs a coordinated strategy on the exploration of dark energy, both space- and ground-based.

To ensure that Europe maintains a leading role in and promotes the progress of this important and exciting field, it is essential that CERN Council and ApPEC coordinate their strategies.

8 Flavour physics and low-energy precision measurements

> Flavour physics and precision measurements at the high-luminosity frontier at lower energies complement our understanding of particle physics and allow for a more accurate interpretation of the results at the high-energy frontier; *these should be led by national or regional collaborations, and the participation of European laboratories and institutes should be promoted.*

Flavour phenomena range from the physics of strange, charm, bottom and top quarks, over mass-hierarchy and quark-mixing physics, to CP and T violation, and possibly to the genesis of the leptons and baryons that constitute our matter world. The existence of flavours gives the SM its family and generation structure. Flavour physics requires both the search for rare processes, and precision measurements. Increased sensitivity and greater accuracy will push even further our confidence in the SM, or lead to the discovery of new phenomena. A flavour-physics programme is a necessary complement to the direct searches for new physics at the high-energy frontier. Increased sensitivity and accuracy requires a new generation of facilities and a matching effort on the theoretical side for an accurate interpretation of the data.

The discovery of neutrino oscillation boosted the importance of precision measurements and the search for rare phenomena in the charged lepton sector. Important areas in this field are: the search for non-(V-A) currents in τ and μ decays, universality violations in the couplings of the charged leptons, and of course the quest for lepton flavour violation (LFV) through neutrinoless τ and μ decays, as well as CP-violating electric dipole moments.

8.1 Flavour physics, CP violation and lepton flavour violation at a very high luminosity B factory

B physics, with its direct access to the third generation, is an ideal window through which to gain information about the flavour structure of physics beyond the SM and of CP violation. Measurements at a high luminosity B-factory are complementary to LHC and ILC. A 50-fold increase of available statistics (to 50 ab^{-1}) compared with presently running B factories will allow very precise measurements of CKM sides and angles, in particular α, which cannot be easily accessed at other planned or existing facilities. Such a facility will also substantially improve the sensitivity to many rare decay modes of B and D mesons, and of the τ lepton (in particular the very important LFV $\tau \rightarrow \mu\gamma$ decay), which are indirect probes of new physics beyond the SM and its flavour sector, in particular SUSY. The presently available proposal for the upgrade of the existing KEK facility has reached a mature technical state, while alternative solutions requiring feasibility studies and extensive R&D are being actively pursued.

European contributions to such a very important regional project should be encouraged. A matching effort on the theoretical side, in particular lattice gauge calculations, is necessary to provide inputs for accurate interpretation of the experimental results.

8.2 Precision physics at low-energy e^+e^- facilities

A very precise measurement of the e^+e^- total cross section allows the evaluation of the hadronic contribution to the anomalous magnetic moment of the muon (g-2), an important probe of physics beyond the SM, and the improved determination of the running coupling constant α_{EM}, an essential ingredient of many precision tests of the SM. In addition, tests of CP, T, CPT discrete symmetries, as well as tests of the validity of quantum mechanics in interference and coherence phenomena with neutral kaons, are possible at a high-luminosity ϕ-factory.

All this information is necessary for our understanding of particle physics and for a precise interpretation of the energy-frontier results. It is very important to maintain a strong suite of local facilities allowing such measurements in Europe. National funding agencies should be encouraged to support initiatives using local laboratory facilities for such low-energy precision measurements. Collaboration between the local laboratories, and with CERN, will strengthen European particle physics and should be enhanced.

8.3 Precision physics with electrons, muons, neutrons and kaons

Charged-lepton flavour violation processes are predicted by several BSM theories, and naturally emerge in grand-unified supersymmetric models of neutrino mixing. In addition to the already mentioned searches for $\tau \rightarrow \mu\gamma$ decays, LFV signals could emerge from the search for $\mu \rightarrow e\ \gamma$ transitions, where a new experiment is about to start, and future facilities sensitive to the alternative $\mu \leftrightarrow e$ conversion on nuclei are being discussed.

Electric dipole moments of neutrons, muons and electrons will be looked for with unprecedented sensitivity. This will further validate the predictions for T violation in the SM, or establish the existence of new T violation mechanisms, as anticipated in many models of physics beyond the SM. Therefore it is important to have several local facilities making these measurements.

Kaons have triggered in the course of the years major advances in particle physics, ranging from the discovery of strangeness, to the first observation of CP violation. They are still a source of possible surprises, being sensitive probes of new physics through their rare decays, like $K \rightarrow \pi\nu\nu$, or via possible LFV final states. The CERN fixed-target beam complex has had many successes in this field and offers good opportunities to continue contributing to this research programme, which should be supported.

The measurements of very rare FCNC decays, the detection of new CP-violating phases, and of electric dipole moments of neutrons, electrons and muons could become primary tools to extract information on the particles and interactions once the new physics is discovered. Therefore it is very important to support projects at local facilities and at CERN that can contribute to this field.

9 Strong interactions and the interface of particle and nuclear physics

> A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

QCD plays a multiple role in particle physics. On one side QCD is one of the cornerstones of the SM, and in spite of its phenomenological successes more work is necessary to fully establish its quantitative predictions in the long-distance and strongly interacting regimes. On the other side, QCD is a crucial tool for the measurement of the electroweak parameters of the SM (e.g. the quark masses and mixings) as well as to search for BSM phenomena, both at low energies (e.g. in the decays of *K* or *B* mesons) and at high energies, where the production of new heavy particles may be hidden by large QCD backgrounds, and often manifests itself in the form of multijet signatures. Finally, QCD leads to new states of matter, when temperature and densities exceed the values beyond which quarks and gluons are confined inside hadrons. Progress in the field of strong interactions, guaranteed by a diversified programme of national or regional facilities operating at different energies and with different beams, plays an important role in the future of particle physics.

9.1 Spectroscopy and strong interactions at large distance

The complete understanding of the confinement mechanism remains one of the key open issues in QCD. In addition to lattice QCD, new theoretical techniques based on string theories are being developed to address it. The experimental confirmation of the existence of glueballs and the clarification of the nature of the recent indications for exotic states will provide important elements to the picture of strong interactions. The interplay between phenomenological models and observations at the proposed facilities can be very fertile for the field. Within Europe, planned experimental programmes in this area include fixed-target experiments at CERN, e^+e^- collisions at LNF in the range $\sqrt{s}$=1-

2.4 GeV, and proton-antiproton collisions at up to $\sqrt{s}=5$ GeV at FAIR-GSI. These initiatives are proposed by established collaborations, operating in the context of national (LNF) or regional (CERN and FAIR) efforts. Similar studies are being carried out or planned outside Europe, and are a component of the programme of the present and future *B* factories.

9.2 The nucleon structure

The rise of the parton densities at small *x* discovered at HERA, which has stimulated numerous theoretical developments, will be further explored at the LHC. Observation of the predicted saturation of parton densities at very small *x* is a very important topic, whose complete exploration would require new facilities like the Large Hadron-electron Collider (LHeC) or electron-nucleus collisions at eRHIC.

The very important topic of the understanding of the spin structure of the nucleon will require further studies with both longitudinally and transversally polarized targets. The Generalized Parton Distributions, which give insight into the transverse spatial distribution of partons, are necessary to unravel the contribution from the orbital angular momentum of partons. Their measurement in different kinematic domains, at the SPS, FAIR, JLAB and eRHIC, is very important.

There is renewed interest in measurements of the electric and magnetic form factors of the proton, following the recent observation at JLAB of the strong Q^2 dependence of their ratio. Their direct measurement is planned at FAIR, and is a potential goal of the DAFNE energy upgrade, which could also ensure the determination of the neutron form factors.

9.3 Diffraction and forward physics

The diffraction process is of interest for a deeper understanding of QCD dynamics. The discovery of rapidity-gap events at HERA has triggered interest in hard and soft diffraction. This has made diffractive processes in a wide range of *x* and Q^2 particularly attractive for a reliable extraction of diffractive parton distributions. The comparison of diffraction in ep and pp processes is an important issue, highlighted by indications of a discrepancy between the HERA and Tevatron data. The small *x* and large Q^2 values probed in pp collisions by the LHC could find an interesting match in the data from LHeC.

Quasi-exclusive diffractive production of Higgs bosons or other new particles at the LHC might prove very important for establishing the charge conjugation and parity quantum numbers of such particles, as well as for an accurate measurement of their mass.

Forward physics at the LHC is interesting in itself and will also help to bridge the gap between ultrahigh energy cosmic rays (UHECRs) and laboratory physics, by providing a more accurate description of hadronic showers, which are a key ingredient in the measurement of the energies of cosmic ray primaries.

9.4 Large Hadron-electron Collider

The LHeC would collide a 70 GeV electron beam with one of the LHC proton or ion beams. Its physics programme would cover the high-precision measurement of parton distributions and diffractive phenomena over a range of *x* and Q^2 much wider than at HERA and relevant for the physics of the LHC. In addition, the large electron-parton center-of-mass energy would allow the production and study of new particles such as leptoquarks, in mass regions so far unexplored. The electron-nucleus part of the programme would explore a regime of very-large parton densities where striking saturation effects could be observed. Both in the case of the exploration of new physics, and of the improvement of our QCD knowledge, input from the LHC will be necessary to evaluate the scientific potential of this facility.

This is a major upgrade of the LHC accelerator, which would require effort at a regional or global level, extended over a long time-scale. At this early stage, studies are underway to determine its technical feasibility.

9.5 QCD as a tool for the exploration of new phenomena

Accurate QCD calculations will be a necessary tool to explore the phenomena exposed by the LHC and e^+e^- linear colliders. New strongly interacting particles, such as gluinos and squarks, decay to multijets, and the measurement of their properties (e.g. masses) requires for their understanding the proper modeling of these final states. QCD processes provide large backgrounds to new physics, and QCD effects (higher-order radiative corrections as well as the modeling of hadronization) affect the extraction of fundamental quantities from the final-state observables. It is therefore fundamental to improve the theoretical understanding of higher-order corrections, of the simulation of the final states, and of their respective systematic uncertainties. This should ultimately lead, for example, to more accurate determinations of α_s and of the top mass in e^+e^- collisions, and of the Higgs couplings at the LHC. The currently available experimental input will be extended by the future colliders, to provide the necessary feedback to and validation of the improved theoretical calculations. The knowledge of the partonic densities of the proton will be an essential ingredient for the LHC; the LHC data will contribute to improving this knowledge. Whether additional experimental input from new deep-inelastic facilities will be required to clarify outstanding issues can only be assessed after the LHC data have been studied.

9.6 New states of matter at high temperature and density

The heavy ion programme at the LHC will greatly extend the exploration and understanding of strong interactions and of the QCD phase diagram, probing deconfined quark-gluon states of matter. The completion of the LHC programme with collisions among several different ion species and at different beam energies, possibly exploiting higher luminosities, will be very important, and should be ensured in the planning of the LHC operation and upgrades.

In parallel, a fixed-target programme, to specifically address the problem of identifying a QCD critical point by improving and diversifying the available data, could be important. The ability to carry out fixed-target experiments at CERN with heavy ions beams should be preserved.

9.7 The interface with the NuPECC road map

There is a well established collaboration on the nuclear physics programme at ISOLDE and a large overlap has developed over the years between the studies of strong interactions covered by the particle and nuclear physics communities. Several of the experimental studies reviewed above are central to the NuPECC road map. Hadronic spectroscopy (e.g. searches for glueballs and exotica) and the study of the proton structure (GPDs and form factors), are proposed for the proton-antiproton programme of the FAIR facility at the GSI. Parts of this programme are common to possible future activities with the SPS fixed-target beam and with DAFNE2. FAIR's heavy ion programme will focus on the QCD phase diagram in the region of extreme baryon densities, a region complementary to that explored by SPS, RHIC and LHC experiments. Close coordination of the respective programmes by the particle and nuclear physics communities will allow the optimal exploitation of the physics potential.

NuPECC's support for the heavy ion programme at the LHC, as formulated in their road map, is welcomed.

10 Theoretical physics

> European theoretical physics has played a crucial role in shaping and consolidating the Standard Model and in formulating possible scenarios for future discoveries. Strong theoretical research and close collaboration with experimentalists are essential to the advancement of particle physics and to take full advantage of experimental progress*; the forthcoming LHC results will open new opportunities for theoretical developments, and create new needs for theoretical calculations, which should be widely supported.*

Theoretical physics and phenomenology underpin the research programme outlined in the previous sections. Since the formulation of the SM, theoretical physics has explored its conceptual extensions, proposing many of the experimental tests that motivate the current and future particle physics programme, and phenomenology has developed the tools required for the interpretation of the data.

Research in theoretical physics is extremely stimulating and challenging, and therefore attracts some among the most brilliant students, whose career opportunities in Europe should be enhanced. The purpose of this section is not to look at the scientific programme of theoretical physics, but to examine what is needed in Europe to enable it to continue flourishing and playing a guiding role worldwide.

The actions proposed below address this goal, identifying a few issues that could help in improving the standing of European theoretical physics. They are addressed not only to the funding agencies and to the EU, but also to the community of senior scientists, whole role in attracting, forming and selecting the next generation of young researchers is critical.

10.1 Promoting interaction between theory and experiment

Future LHC results will generate new challenges and opportunities for theoretical physics, and require closer cooperation between theorists and experimentalists. To improve this interaction it is necessary to start at an early stage, with the teaching of final-year undergraduates, to make them aware of the exciting new opportunities for theoretical work in interpreting the new phenomena exposed by the experiments. This could be favoured by suitably adapting the contents of the particle physics courses, giving greater emphasis to the interplay between theory and experiment, and continued for graduate students and young post-docs with more Summer Schools targeted at both experimental and theoretical students.

10.2 Improving flexibility and maintaining diversity of career paths

The research activity of young theorists is too often driven by the need to secure a permanent position, which can constrain their choice of an original research topic. The evaluation of their activity forced by the current career structures discourages on the one hand creativity and risk taking, and on the other hand the pursuit of fundamental complex and time-consuming calculations. Improving flexibility, for example by adapting the terms of postdoctoral contracts to suit the needs of long time-scale projects, while maintaining diversity in career paths, would be beneficial. When assigning positions, a greater weighting of the level of difficulty and originality relative to the number of produced publications could better reward risk-taking in the choice of research topics.

10.3 Changes in the working environment of theory groups

Innovations in workplace design have proven successful in theoretical physics departments in the US. Apparently minor architectural changes facilitate interaction and generate an atmosphere that more easily leads to both creative thinking and concrete research projects. These models serve as examples of good practice, and can inspire the evolution of the infrastructure of theory groups at Universities and laboratories in Europe.

10.4 Actions at CERN

CERN is a centre of excellence for theoretical particle physics in Europe, with efforts ranging from phenomenology directly connected to the experimental activities, to the development of new ideas pushing the frontier of the field. The theory group at CERN provides a stimulating environment for theorists to meet and discuss, and to interact with the experimentalists on the interpretation of their results. The visitor programme, while maintaining its current role of supporting visits by individual scientists, can assist this process by arranging a number of periods with a targeted and coordinated presence of visitors.

10.5 Support for lattice field theory

Lattice field theory techniques are making significant progress, and play an important role in exploring strong-coupling phenomena in general, leading in particular to an improved theoretical control of low-energy QCD processes. Meanwhile, QCD numerical simulations, which will be very important for the interpretation of the results from flavour factories, need to be supported at an appropriate level to enable the theoretical uncertainties to be brought in line with the experimental precision.

10.6 Role of the EU networks

EU funded networks play an important role in the support of international collaborations in theoretical particle physics. In order to rely on them for strategic planning, a longer time scale of the projects, more certainty in their continued availability, more flexibility in the utilization of the support, and recognition of particle physics as a subfield, are needed. These points should be addressed once the mechanism for communicating strategic issues affecting particle physics to the European Union has been established.

Organizational Issues

11 Taking responsibility for the European strategy for particle physics

> There is a fundamental need for an ongoing process to define and update the European strategy for particle physics; *Council, under Article II-2(b) of the CERN Convention, shall assume this responsibility, acting as a council for European particle physics, holding a special session at least once each year for this purpose. Council will define and update the strategy based on proposals and observations from a dedicated scientific body that it shall establish for this purpose.*

In the increasingly global environment, a common European view on future facilities for particle physics is needed. This is necessary both to develop and enhance European leadership in those areas where it is appropriate for such facilities to be hosted in Europe in partnership with the other regions, and to allow European particle physicists to access unique frontier facilities that are hosted elsewhere. A European strategy for particle physics was drafted at the CERN Council Strategy Group meeting held in DESY-Zeuthen 2nd to 6th May 2006. The Strategy Group was established as an *ad hoc* group that will be dissolved once its task is complete. But it is clear that, once a strategy is agreed and adopted, there must be an ongoing process to maintain and update that strategy.

The CERN Convention, under article II-2 states

2. *The Organization shall, in the collaboration referred to in paragraph 1 above, confine its activities to the following:*

   (a) the construction and operation of one or more international laboratories (hereinafter referred to as "the Laboratories ") for research on high-energy particles, including work in the field of cosmic rays

[…]

   (b) the organization and sponsoring of international co-operation in nuclear research, including co-operation outside the Laboratories; this co-operation may include in particular:

      (i) work in the field of theoretical nuclear physics;
      (ii) the promotion of contacts between, and the interchange of, scientists, the dissemination of information, and the provision of advanced training for research workers;
      (iii) collaborating with and advising other research institutions;
      (iv) work in the field of cosmic rays.

[…]

It is clear that there must be a separation between the operation of the Council when dealing with "*the Laboratories*" (currently the CERN laboratory in Geneva) under 2-(a), and as the custodian of the European strategy for particle physics, when acting under 2-(b). In this second role, Council will become central to the process of defining and updating the strategy, formally approving it and remaining informed about its implementation. At least once per year Council will, in a dedicated session, discuss European strategic issues in particle physics. It will require additional scientific input, and shall for this purpose create a body with the mission to propose to Council updates to the European strategy for particle physics, including a medium- and long-term road map taking into account the resources and competences likely to be available throughout Europe. This body will prepare for Council proposals related to the strategy and will monitor the implementation of the strategy. The relationship between this new body and the existing committees (ECFA, RECFA, ESGARD and the SPC) needs to be defined.

A specific proposal for this body, called the European Strategy Group, was discussed in Zeuthen. It could consist of 15 to 20 scientists, appointed by the Council for a three-year period. Every few years the Council should enlarge the group to include representatives of all member states and major European national laboratories for a specific meeting where the medium- and long-term European strategy for particle physics is reviewed and updated. The strategy should include the major programmes needed in Europe for accelerator and detector R&D. Restricted ECFA should provide input to the strategy, and its chair should be an *ex-officio* member of the group.

The Scientific Policy Committee should continue in the same role as at present, providing scientific input and advice about the CERN Organization. RECFA should continue to monitor particle physics in the CERN member states.

ESGARD should be responsible for the coordination of the accelerator R&D in Europe, report to Council and act as the interface body for European accelerator research between particle physics and the European Commission.

12 European participation in global projects

> Future major facilities in Europe and elsewhere require collaborations on a global scale; *Council, drawing on the European experience in the successful construction and operation of large-scale facilities, will prepare a framework for Europe to engage with the other regions of the world with the goal of optimizing the particle physics output through the best shared use of resources while maintaining European capabilities.*

The scale of the energy-frontier facilities, and perhaps others, is now such that financial and technical responsibilities and risks need increasingly to be shared among the regions. It is probable that these facilities will be organized as global collaborations. In this new environment, it is essential that there is a coordinated European approach, otherwise European influence risks being fragmented and thus diluted. Europe, through CERN and other laboratories such as DESY, has considerable experience in the successful design and construction of large-scale facilities. Council needs to build upon this experience, and prepare a framework for Europe to engage with the other regions of the world in major new research infrastructures, consistent with its strategy for European particle physics. Such a framework is essential if Europe is to contribute to such global projects at an appropriate level, while preparing for the long-term European-based research infrastructure and maintaining a rich and diverse research programme within Europe.

13 Particle physics and the European Union

Through its programmes, the European Union establishes in a broad sense the European Research Area, with European particle physics having its own established structures and organizations; *there is a need to strengthen this relationship for communicating issues related to the strategy.*

European particle physics has its own established structures and organizations, which function well. It is in the context of the European Union that the overall view of European research and research infrastructure is assembled, and the EU Council is the only European forum where all Ministers of Research multilaterally discuss research with a European dimension. The European strategy for particle physics has to be visible in this context.

This is in particular important in relation to the road map proposal that the European Strategy Forum on Research Infrastructures (ESFRI) is preparing for the Commission. It is vital for European particle physics that the excellent relationship with the Commission in the areas of accelerator and detector R&D is maintained, strengthened, and extended to other areas. The mechanism of communication with ESFRI and the Commission on the Council`s European strategy for particle physics must therefore be established.

The framework programmes, with e.g. the Marie-Curie Actions and the emerging European Research Council (ERC), could play an important role in European particle physics. European particle physics, through the Council, needs to be fully engaged in the construction of the European Research Area.

14 Relationship with the observer and non-member states

Particle physicists in the non-Member States benefit from, and add to, the research programme funded by the CERN Member States; *Council will establish how the non-member States should be involved in defining the strategy.*

With the globalisation of the frontier projects, and the emerging need for a European strategy for particle physics, there is a need to take into account the views of the particle physics communities in Europe that are not from CERN member states. There is also a need to decide whether the relationship with the Observer states needs to evolve in this context. The Observer states are very satisfied with the present mode of operation with CERN. Scientists and engineers from the Observer states can, and do, bring important special expertise to CERN, which requires appropriate support at home. There is a desire among the Observer states for enhanced mechanisms for collaboration, for example through special exchange programmes, not only with CERN but with other European laboratories and institutions. Some Observer states (for example, Russia and Japan) would like a global forum for particle physics. With respect to the ILC, Japan is already member of FALC, and Russia, Turkey and Israel would like to be invited in the future.

If Council establishes mechanisms to communicate strategic advice to the EU Commission on particle physics, then the rights and responsibilities of the Observer states need to be defined when the European strategy is discussed in Council.

The Observer states note that the national laboratories and institutions are needed for a diversified and innovative particle physics programme and for educational purposes.

The Observer states foresee difficulties in modifying the ICFA guidelines on access to accelerator facilities, since this would probably require international activity in other branches also to be taken into account.

The creation of SESAME is a very worthwhile scientific undertaking that embodies the values upon which CERN was founded, highlighting the potential added value of a collaboration across boundaries.

Complementary Issues

15 Outreach and education

Fundamental physics impacts both scientific and philosophical thinking, influencing the way we perceive the universe and our role in it. It is an integral part of particle physics research to share the wonders of our discoveries with the public and the youth in particular. Outreach should be implemented with adequate resources from the start of any major project; *Council will establish a network of closely cooperating professional communication officers from each member state, which would incorporate existing activities, propose, implement and monitor a European particle physics communication and education strategy, and report on a regular basis to Council.*

15.1 Communicating the achievements of particle physics

Communication must be an integral part of particle physics research. The results are generated using public resources and form part of our cultural heritage. The excitement of frontier research inspires the ongoing efforts to understand Nature, and it plays an important role in improving scientific literacy on many levels. Effective communication is also necessary to position the field in a competitive environment.

Effective communication begins with the identification of target audiences and the desired effect on those audiences. It continues through the identification and development of key messages, and finally the choice of a delivery mechanism. Ongoing evaluation of the impact of a communication campaign should also not be neglected.

Audiences are very diverse, but the underlying core messages should be the same. Good communication is factually accurate but adapted to the knowledge and interest of the target audience. In Europe, culture and language play an important role. Communication should be delivered in the language of the receiver wherever possible. Good communication is also timely. Communication campaigns should be timed to coincide constructively with events beyond the field where possible, and to avoid clashing with major news generators, such as G8 meetings for example.

Many scientists are very willing to communicate. This should be encouraged and supported both through specific actions such as communication and media training, and through the appropriate recognition of the value of communication in the career development. Some countries and institutes offer communication training, and this practice should be more widely adopted. Greater coordination is required to put scientists who are good communicators in contact with audiences through, for example, existing science centre networks or laboratory press offices. On the European scale, the creation of a network of communication officers from each Member State, along the lines of the global InterActions network of laboratory communication officers and complementary to the European Particle Physics Outreach Group (EPPOG), could play this role. Currently, such an ad-hoc network exists for a number of countries and is supplemented by the EPPOG delegates for the remaining ones.

The formalization of such a network would help to ensure that maximum benefit is secured from the considerable, but disconnected, effort already being made at the national level. The network would not be dominated by any one laboratory, but could be organised along similar lines to EPPOG, with a rotating chair and administrative support from CERN. It would be natural for such a network to report on a regular basis to the CERN Council as the coordinating body of European particle physics. It would work closely with EPPOG and with the InterActions network.

Communication should be part of large projects from their onset. A good example of such a strategy is the communication of the ILC. This has been part of the project from the beginning, it is globally coordinated and adequately resourced with dedicated communication officers for the American, Asian and European regions. For the LHC project, communication was not included from the outset and is only beginning in earnest now. Good, coordinated, communication of the LHC start-up and results will be vital for the continued good health of particle physics. This effort has started, but needs to be vigorously pursued over the coming months and years.

In addition to project-based communication, a continuous baseline communication activity should be pursued to develop and maintain interest in and support for particle physics research. The coordination of this activity would again be a natural task for a network of communication professionals working in tandem with EPPOG and the InterActions network.

15.2 Education in schools

There are already many actions ongoing in the various states in Europe. The need to communicate in each country’s language leads to an effort that is naturally national, and very often local. These actions include a number of ways to reach directly children of ages ranging from 10 to university entrance: web sites, videos, posters, special school classes, laboratory visits, virtual experiments and telescopes, master classes, competitions such as the Olympics of knowledge and a variety of teaching material and dedicated newspapers. Many of these initiatives are extremely successful. Personal interactions with students, especially when they involve hands-on experiments and engage the children’s teachers, are considered to have the largest impact on a given student, while posters and children’s publications reach out to a larger number.

Teachers’ programmes are an efficient way to communicate the wonders of science to children of all ages, and have been very well received. Material is available for teachers in the form of web-accessible lectures, animations and prepared projects. The ability of teachers to use this material in their classes can be limited by the fact that education in modern science in often not part of the official curriculum.

There exists a central web site hosted by CERN with links to a number of ongoing activities, but the information flow between initiatives is still considered insufficient and should be reinforced. The need for coordination for a number of specific actions is clear, however individual initiatives are still the preferred means of operation. These initiatives are usually performed by university or laboratory personnel on a voluntary basis. They can entail significant expenses, which constitute a serious limitation.

The European network of communication should be strengthened to maximize the effect of the many efforts already ongoing across Europe, and address specific issues such as:

1. investing a fraction of the funding of university groups or laboratories in education programmes, as is already the case in some European countries;
2. devising a way to measure the impact of the present efforts;
3. including education in modern science in the school curriculum at an appropriate level.

16 Technology transfer, knowledge transfer and computing

> Technology developed for nuclear and particle physics research has made and is making a lasting impact on society in areas such as material sciences and biology (e.g. synchrotron radiation facilities), communication and information technology (e.g. the web and grid computing), health (e.g. the PET scanner and hadron therapy facilities); *to further promote the impact of the spin-offs of particle physics research, the relevant technology transfer representatives at CERN and in member states should create a technology transfer forum to analyze the keys to the success in technology transfer projects in general, make proposals for improving its effectiveness, promoting knowledge transfer through mobility of scientists and engineers between industry and research.*

The tools required for particle physics research have generated waves of technological innovations and applications throughout the sciences and society. The competences and skills developed through training in particle physics can be successfully transferred to other disciplines and sectors. These issues are briefly discussed here, and are illustrated in greater detail in Chapters XI and XII of Briefing Book I.

The world's most powerful accelerators are among the largest and most technologically sophisticated experimental devices ever built. The thousands of small accelerators used in hospitals to generate X-rays for radiation treatment come from designs developed for particle physics. These designs have been improved and refined as research on accelerator technologies for forefront science has continued to be applied to medical accelerators. Accelerators also are used to produce radioisotopes for treatment, diagnostic tools, and research, and technologies developed for detecting particles in high-energy physics experiments have had important applications in medical imaging.

In industry, accelerators are used for R&D, manufacturing, testing, and process control. For example, beams from accelerators are used to alter the composition of materials and to improve the characteristics of products. Uses of accelerators range from the dating of archaeological samples to the simulation of cosmic rays to determine the impact of radiation on space-based electronics.

When energetic charged particles pass through curved paths in a magnetic field, they generate radiation. The ability of accelerators to produce powerful beams of X-rays or photons of differing energies has generated applications across a broad range of science. Accelerator X-ray sources provide, for example, the ability to decipher the structure of proteins and other biological macromolecules, and to find trace impurities in the environment or on the surface of a silicon chip. The science produced by these experiments has found applications throughout industry and medicine.

In general, particle physics contributes to — and depends on — advances in other areas of physics (such as nuclear physics and condensed-matter physics) and in many other scientific fields, including materials science, computing, biology, chemistry, and nanoscience. The health of science requires support of all parts of this interlocking web.

Technical challenges faced by particle physicists — such as processing millions of signals quickly, using distributed computers to solve complex problems, and generating electromagnetic fields to accelerate and confine charged particles — have led to many spinoff technologies. Particle physics also has contributed in important ways to mathematics, even as mathematics has been used to understand the theoretical structures describing particles.

Finally, because particle physics addresses some of the deepest questions that humans can ask, it resonates strongly with the public at large. The science shelves of bookstores teem with popular expositions of the current understanding of these issues, and many students are attracted to science because they are interested in issues addressed by particle physics.

Technology transfer (TT) from particle physics to society has had several successes but also less succesful projects. The factors that determine the success have not been thoroughly analyzed. It would therefore be valuable to review in detail and document the successful and unsuccessful TT projects and procedures in particle physics by setting up a structural forum. This could be done by the CERN ITT office together with national representatives. Furthermore it would be beneficial to create structural platforms and opportunities for researchers from particle physics and industry to meet.

Public awareness of the extent and value of the TT from particle physics research to the society should be enhanced. Concretely, the following initiatives could be useful:

- Recognition of the value of scientists and engineers trained in particle physics research for industries and society should be encouraged.
- Creation of an award given together by CERN and industry for a successful TT project to a researcher.
- Exploration of the possibility to use funds from EU programmes to support temporary positions in TT at a network of particle physics laboratories.

Particle physics plays a particularly important role in enabling new computing technologies. These have proven relevant to the information society, in particular to allow the handling of large data sets, and to society at large, as underscored by the example of the World Wide Web. The development of computing technologies, with the attendant benefit to other fields of science and to society, should be actively promoted.

17 Particle physics and industry

> The technical advances necessary for particle physics both benefit from, and stimulate, the technological competences available in European industry; *Council will consolidate and reinforce this connection, by ensuring that future engagement with industry takes account of current best practices, and continuously profits from the accumulated experience.*

The major particle physics construction projects, like the LHC, depend upon industry to provide much of the volume production, for both the accelerators and the detectors. Much of this work involves advanced technology or engineering, at the leading edge of what is currently achievable. Often, the developments showing that required performance can be achieved took place in a particle physics laboratory or institute, and the relevant technologies had then to be transferred to industry for prototyping and production. There are very many examples, in both the accelerator and detector areas, where this process has been very successful. However, in a small number of cases, some with a fairly high profile, this process has encountered difficulties. It is essential that the causes of these difficulties are understood, and action taken to minimise such risks in future. It would therefore be valuable, once the LHC construction is complete, to examine critically some contracts (some that were entirely satisfactory and some that met serious difficulties) to look for examples of good and poor practice, and to see what lessons can be learnt from the experience. More generally, it is suggested that Council should take steps to ensure that future engagement with industry takes account of current best practices, and continuously profits from the accumulated experience.