Organisation for Economic Co-operation and Development
Global Science Forum

Report of the

Consultative Group on High-Energy Physics

June 2002

I. Executive Summary and Principal Conclusions

The OECD Global Science Forum (GSF) established the Consultative Group on High-Energy Physics in June 2000. Its remit was to exchange views on the future directions of high-energy physics (HEP) particularly as regards large facilities, to examine the rationale behind programme priorities and strategies, to look at common or generic issues and approaches, and to identify and discuss relevant organisation and managerial issues. It was to submit a report to the GSF in June 2002.

Participating governments nominated delegates. In the interests of openness and transparency, and to ensure that the Group's findings were based on the best information, non-OECD countries were invited to send delegates. Further, representatives of the main scientific communities were invited to take part in all the meetings and discussions on an equal footing with the national delegates. Four meetings were held at leading HEP laboratories world-wide.

The Group found the input from the communities invaluable in providing the scientific background to its debates. HEP is at a critical stage in its development. The "Standard Model" is a major, well documented intellectual achievement, but experimental data and observations show it to be incomplete, leaving many important questions unanswered. Astrophysics and cosmology have advanced in parallel to produce what could also be called a standard model of the Universe, but recent observations have raised very fundamental questions about the early stages of the Universe and its fundamental composition in terms of matter and energy. These are questions that can be addressed by advances in HEP. But it is generally accepted that the next generation of facilities that will be needed to probe physics "beyond the Standard Model" will require a changed paradigm, from national or regional facilities exploited internationally, to inherently global projects that will be fundamentally different in their basic organisational concepts.

The Group was impressed by the range and depth of the studies carried out by the world-wide HEP communities in setting out the scientific and programme priorities over the next several decades, and by the degree of consensus between the communities in all regions. There is complete agreement, demonstrated in reports from Asian, European, North American, and International bodies, that the next large accelerator-based facility is an electron-positron linear collider (LC), operating concurrently with the Large Hadron Collider (LHC) proton-proton collider now being constructed at CERN and due to start operation in 2007. The Group found the scientific arguments presented by the communities to be compelling. The Group noted that there were four technological options open for the design of such a machine, and that these were being vigorously investigated through internationally collaborative R&D programmes world-wide.

Based on the input from the communities, the Group has constructed an HEP Road Map extending to beyond 2020. This is provided as an indicative framework, intended to inform regional and national discussion of the generic issues and possible timescales required for their resolution. The agreement amongst physicists on the linear collider as the next step in HEP suggested to the Group that there was a powerful argument for the communities to establish global scientific and technical co-ordination mechanisms. The Group agreed that the estimates of project costs and timescales for the LC were reasonable and broadly comparable to those of the LHC, and that the cost could be accommodated if the historical pattern of expenditure on particle physics is maintained, taking into account the additional resources provided by the host country (or countries).

The Road Map focuses on accelerator-based HEP, because it is here that the generic issues addressed by the Group are most evident. The Group heard from representatives of the astroparticle physics community that it is growing rapidly world-wide, with ambitious experiments ranging from deep underground facilities to space-based detectors. The Group felt that the generic issues being addressed in the context of accelerator-based facilities could apply equally well to large astroparticle physics installations should they become sufficiently large and complex.

The impressive progress in HEP, astrophysics, and cosmology has relied on equally impressive technological advances in accelerator science, detector technology and information processing. It is hardly surprising that a common theme to emerge from all studies was the need for sustained long-term R&D programmes, and the Group noted how advances in technology developed for HEP had benefited other fields of research and now saw practical applications in disparate fields such a biology, medicine and materials science. The Group regarded the maintenance of vigorous long-term R&D programmes as a generic issue to be addressed by governments, agencies, and intergovernmental organisations in the broad context of future investment in HEP and the maintenance of vigorous national and regional programmes.

Starting with two Working Groups, a wide range of organisational and managerial issues associated with the creation of a major new international HEP facility were studied. These are all areas where work will be required of the proposers of such projects and the participating governments. There was common agreement that any new facility should draw on current strengths and should not weaken national and regional communities. The Group recognised that solutions could well vary from proposal to proposal, and from region to region, but that there was sufficient commonality for work to start now, if the timescales desired by the communities were to be realised.

Specific issues highlighted in the discussion included: legal structure, financial arrangements, managerial structure, reporting and accountability, roles of the host nation and the host laboratory. The Group reached no firm conclusions on any of these issues, but explored possible structures and ways forward.

A key issue that is already being discussed by the communities is the mechanism whereby international negotiations on the next steps towards a linear collider can be started. The Group looked at the ways in which community driven initiatives offering different technological approaches to common scientific objectives might be reconciled to converge on a global consensus and, ultimately, funding decisions. In simplified terms the Group saw two generic routes. One involves regions or countries competing, each with a specific design, for local government support, with the global project ultimately going to the first to reach a critical level of financing. The other approach involves the communities reaching a consensus on the scientific goals and technological approach, turning to governments for financing, and ultimately leaving it to the governments to decide on funding and location. The Group examined examples of both approaches, and agreed that the underlying dynamics of both approaches had a part to play in the evolution of HEP, but that ultimately the role of governments in reaching a final decision was crucial and that timely involvement would be advantageous.

The Group also noted that the impressive progress in HEP, astrophysics and cosmology was due, in very large measure, to the extraordinarily high quality of the people attracted to these fields. Such people must continue to be attracted, and in the increasingly competitive modern environment, where all areas of science, commerce, and industry are seeking to attract the most creative minds, HEP must continue to give a real priority to education, outreach and public awareness. This is not only to educate opinion formers and decision makers but also to convince the best young people of the value of HEP as both an intellectual exercise and as a career.

The Group concluded that the consultative exercise had been both useful and productive. Through its discussions national delegates had first hand appreciation of the extremely healthy intellectual state of HEP and of the work done by the scientific communities, and could now understand the global consensus on plans for the future. The meetings had identified a series of generic issues which needed to be addressed by the communities and governments, preferably working in concert. The consultative format of the meetings had stimulated a debate between scientists and government delegates on decision making processes, resulting in greater mutual understanding and a consensus on the issues to be addressed if the next major HEP facility, the linear collider, is to become a reality.

Principal Conclusions of the Consultative Group

- Regarding the Road Map for High-Energy Physics:
    - The Consultative Group concurs with the world-wide consensus of the scientific community that a high-energy electron-positron linear collider is the next facility on the Road Map.
    - There should be a significant period of concurrent running of the LHC and the LC, requiring the LC to start operating before 2015. Given the long lead times for decision-making and for construction, consultations among interested countries should begin at a suitably-chosen time in the near future.
    - The cost of the LC will be broadly comparable to that of the LHC, and can be accommodated if the historical pattern of expenditure on particle physics is maintained, taking into account the additional resources that the host country (or countries) will need to provide.
- Regarding International R&D Co-operation:
    - The long-standing productive ties between the HEP laboratories provide a sound basis for establishing, as needed, formal collaborations for targeted and effective R&D for selecting the technologies and conceptual designs, and for jointly working out the detailed technical specifications of global-scale projects. Such a need currently exists for the e+e- linear collider that is to be realised through global collaboration.
    - To ensure the long-term vitality of particle physics as described by the Road Map, a diverse accelerator R&D programme should be maintained. Innovative accelerator concepts should be explored well before they may be needed, since the lead times for large, complex new projects span decades, and the unpredictable course of discovery in physics may shift the currently foreseen priorities of the facilities on the Road Map.
- Regarding Organisational and Managerial Issues Associated with Creating a Major New International High-Energy Physics Facility:
    - Preparing and negotiating a formal agreement (or a series of agreements) for the design, construction and operation of a facility on the scale of a linear collider is very time-consuming. Past experiences (in high-energy physics and in other domains) show that several years may have to be devoted to consultations and negotiations that are the responsibility of governments. Such a process is, to a large extent, independent of, and complementary to, the scientific discussions that are needed to establish the scientific and technological goals and parameters of the project. Therefore, it is important to allow sufficient time for inter-governmental consultations, well before any financial, manpower, timeline, or other commitments are made.

- For a large collider project, the generic criteria for, and contents of, the agreement(s) between international partners have been enumerated by the Consultative Group: legal basis of the project, management structure, special role of the host laboratory/host country, personnel provisions, financial arrangements, procurement practices, accelerator-detector interface, intellectual property, liability, accession of new participants, and others. Within each category, issues and options can be identified now, but the actual details of a final agreement cannot be foreseen at this time, since they will emerge in the course of inter-governmental negotiations based on the negotiating positions of the participating governments.

- A critical but still unresolved issue is the method for initiating the negotiating process for a linear collider. There currently exist several competing design approaches, and the scientific communities of at least three countries have expressed interest in hosting the facility. Current process to establish the ITER fusion project and the ALMA radio telescope array may provide valuable insights on how to proceed with a global high-energy physics facility, both with respect to the negotiating phase, and the subsequent facility construction, operation and management.

- While the work leading to this report was carried out under the aegis of the OECD, participation in a global high-energy physics facility such as the linear collider should be open to any government with an interest and capability to participate.

II. Introduction/Rationale

High-energy physicists seek to identify the elementary constituents of matter and to discover the fundamental laws of Nature. These are among the most profound inquiries of the entire scientific enterprise. The field is exciting both intellectually and practically, with close links to other areas of basic and applied research. High-energy physics (HEP) has contributed to the development of many valuable applications, for example, linear accelerators for cancer therapy. High-energy physics has also promoted international understanding through global scientific collaboration. For many countries, support for HEP has been a vital component of a national science policy aimed at advancing the frontiers of knowledge, ensuring prosperity and competitiveness, and training a highly-skilled workforce. Governments have a strong interest in maintaining the vitality of this field, as they have done for over fifty years[1].

Today, the field of high-energy physics is transforming itself in two ways: into a new period of scientific discovery, and to new forms of organisation and collaboration:

- As a scientific domain, HEP has made remarkable progress in the last five decades to arrive at a small set of basic constituent particles of all matter in the Universe and four kinds of interaction between them. These achievements are summarised in the "standard model of particles and their interactions" (the Standard Model), one of the great scientific achievements of the 20th century. The model, however, is known to be incomplete, and the scientific community is eager to probe even deeper into the fundamental properties of Nature, using powerful new techniques and devices.
- Given the likely cost of the needed new facilities and related technology development, future progress in the field will likely require that some of the facilities be planned and implemented on a global basis. This is true for both accelerator and non-accelerator approaches to HEP.

Recognising these important trends in the evolution of HEP, the delegations to the OECD Global Science Forum agreed to conduct consultations about the future of the field and the opportunities offered by strengthened international co-operation on major facilities. While realising that such consultations already take place in the scientific community, it was considered important to promote interactions among policy officials and programme managers who are responsible for preparing long-range priorities and funding plans, and for co-ordinating these plans with those of science policy officials in other sectors. Accordingly, delegates to the third meeting of the OECD Global Science Forum in June 2000 authorised the establishment of a Consultative Group on High-Energy Physics, based on a proposal from the delegations of the United Kingdom and the United States. The Group was asked to conduct meetings and studies as necessary and to develop findings and conclusions for participating governments within two years. While acknowledging the value of small- and medium-scale facilities and experiments, the Consultative Group concentrated on <u>future large, energy-frontier, accelerator-based facilities</u> whose realisation will depend on strengthened international collaboration.

The Consultative Group developed findings and recommendations for actions by participating governments, but the recommendations are not intended to be prescriptive, and the responsibility for final decisions will continue to rest with governments, or bodies formally constituted by them.

[1] Annual funding of HEP world-wide is approximately 2.5 billion USD, which constitutes some 1.5% of the global government expenditures on R&D.

III. General Findings Regarding High-Energy Physics

A. Emerging Scientific Vision of the Future of HEP

The Standard Model describes the interactions of the known particles with impressive precision, but it does not explain, for example, the relative strength of the interactions, or the large differences between the particle masses. This has led to even deeper unanswered questions: Why is there such a simple pattern to the constituents? How do they acquire different masses? Why does the universe contain apparently only matter but no detectable antimatter? How can gravitational forces between the constituents be incorporated into the Standard Model? Are all the interactions, including gravity, just manifestations of a single, more basic theory? Could the incorporation of gravity lead to the discovery of extra dimensions, beyond the currently known four dimensions of space and time, but so far hidden from us? It will be possible to begin answering these questions using the facilities described in this report, thus opening a new era of discovery in physics.

In contemplating future developments beyond the Standard Model, members of the scientific community have acknowledged the need for a unified strategic vision of the entire field, both as an aid to their own research, and as a planning tool for science policy officials who will have to make decisions about implementing specific projects and programmes. During the past year, scientific and advisory bodies in various parts of the world have held independent consultations about the future of the field. They have sought to identify the most pressing scientific questions, to enumerate the tools and techniques that will be needed to answer those questions, and to set realistic short-, medium-, and long-term priorities for moving forward in an efficient and cost-effective manner. Two complementary lines of approach have been identified:

- Non-accelerator particle physics (primarily astroparticle physics). This new interdisciplinary approach uses the Universe as a laboratory, with physicists applying the Standard Model (and its possible extensions) to the primordial Universe and to its particle content. Discoveries in the field of cosmology have a direct impact on a better understanding of particle physics and vice versa (the “dark matter” problem is an example of this interaction). Also, the study of ultra high-energy cosmic ray particles allows physicists to access energies which cannot, at present, be achieved using accelerators. Finally, new windows on the Universe can be opened with neutrino, gamma-ray and gravitational wave astronomy. There have been enormous advances in the understanding of the properties of neutrinos from a variety of non-accelerator experiments using solar and atmospheric[2] neutrinos, as well as neutrinos from reactors. The discovery that neutrinos have non-zero masses, and that they convert from one type to another, has provided tantalising clues to new theories beyond the Standard Model. Presently, the experiments in non-accelerator particle physics are addressing fundamental issues with small- and medium-scale experiments funded at national, or regional or sometimes international level. This complements the accelerator-based approach.
- Accelerator based particle physics. From the science policy perspective, the most significant development is the emergence of a coherent strategy regarding the large, expensive accelerator-based facilities that will, at any given period in the future, operate at the highest-energy frontier. Despite the ongoing importance of medium-scale experiments, the gradual concentration of HEP research around these very large facilities and experiments will continue to change the way the field is organised and managed, and the way it is experienced by the physicists themselves. As in the past, results obtained at the large front-line facilities are expected to lead to the development of theories that will

[2] “Atmospheric neutrinos” are produced when cosmic rays (primarily protons) collide with nuclei in the Earth’s atmosphere. This creates a large number of hadrons (mostly pions). The pions decay into muons which, in turn, decay into either positrons or electrons. Each decay also produces neutrinos.

explain a wide range of lower-energy observations, as well as revealing entirely new (perhaps unexpected) phenomena that will lead physicists in new directions.

Thanks to the recent efforts of the scientific and advisory bodies, there is now a clear international consensus vision of the future of accelerator-based facilities. The key challenge to policymakers is to conduct the appropriate discussions at the national, regional and global levels, with a view to establishing the needed experimental facilities within realistic time and budget envelopes, taking into account other scientific priorities and projects. The global Road Map developed in this report provides some of the input that will be needed to addresses this challenge.

B. <u>Prospects for Strengthened International Co-ordination and Collaboration</u>

High-energy physics has traditionally been characterised by, and benefited from, a highly developed network of international collaboration, and international exchanges of personnel, ideas and equipment. For the most part, however, major accelerator facilities have been conceived, funded, and built on a national basis (or, in the notable case of CERN, as a regional collaboration). The future vitality of HEP will continue to depend on strong national programmes, and there will be a continuing role for national and regional facilities. However, as regards the largest, most advanced facilities, the field is entering a new phase, where the needed financial and intellectual resources will exceed those available on a national, and even regional, scale. Accordingly, governments will have to develop new institutional and organisational frameworks for future global HEP collaborations. This will be a difficult task, requiring the harmonisation of existing national and regional procedures within which big, complex, expensive projects are developed and operated. Section VI of this report enumerates some of the organisational and managerial issues connected with global accelerator collaborations.

Although most of the resources for a global-scale collaboration will come from countries that already have significant HEP programmes (that is, for the most part, the countries that participated in the deliberations of the Consultative Group) there is the potential for important contributions (for example, intellectual contributions, software expertise, labour) from smaller countries, or countries without a long history of activity in the field. Some of these countries are already contributing to the construction of the Large Hadron Collider (LHC) at CERN. In many cases, physicists from these countries have participated in experimental programmes at some of the largest HEP facilities. For these reasons, all countries should have an opportunity to participate, at the earliest stages, in discussions about the scientific, technological and administrative aspects of future large collaborations.

The establishment of a global-scale collaboration will require intense negotiations on the managerial, administrative, and financial aspects of the project. A case in point is the highest-priority big project that has been identified by the scientific community: a linear electron-positron collider (LC). Although many technological problems have already been resolved, there is still much work to be done before a final design can be agreed on. But some of the important challenges are those that confront policymakers, not scientists or engineers. In three geographical areas (Europe, Asia, and North America) scientific communities have called upon their governments to host an international collider collaboration within a timeframe that will allow for overlap with the LHC. However, it is not clear at this time how a consensus can be reached on the site of a linear collider, or how the financial resources can be mustered. The deliberations of the Global Science Forum Consultative Group were aimed at exploring these policy issues, and considering the future frameworks within which they can be resolved.

C. Impact on Decision-Making and Facility Planning

As HEP research coalesces around a smaller number of global projects, national scientific communities and science administrations will have to decide on the extent to which they want to become partners in these international undertakings. Joining multilateral projects can lead to a restriction of choices and a certain loss of autonomy. In return, the national scientific community is able to participate in the most advanced research projects and obtains access to cutting-edge technology. Smaller countries are familiar with these trade-offs, but the larger countries will have to make the necessary adjustments, for example, in the way they conduct long-term planning. Perhaps the most difficult decisions will concern the future of the big national laboratories that are (or have been) the site of major accelerators. While a small number of laboratories will continue to host major HEP facilities, others may assume the role of partners in accelerators and experiments that are located far away. Indeed, a large accelerator-based project could be deliberately designed in a way that would maximise the role of non-host laboratories, for example, by allowing remote operation of selected accelerator and detector systems, although this would have an impact on the cost and complexity of the project. The technical feasibility of this "Global Accelerator Network" (GAN) is under consideration by members of the scientific community. Other laboratories may focus on R&D for the more distant future, or evolve towards other fields or research, or perhaps even cease HEP activities altogether. A facility can be "shut down" for the purposes of high-energy physics, and then become a front-line facility for another scientific purpose. For example, electron accelerators have been transformed into synchrotron light sources for basic and applied research, as indicated in the chart that accompanies this report.

The orderly transition to new modes of operation will require a concerted effort on the part of government and laboratory officials, local administrations, and the personnel concerned.

D. Contributions of HEP to Other Fields and to Society

Throughout its history, HEP has been the source of ideas, techniques and devices for a wide range of other scientific and technological fields, both fundamental and applied. A full compendium of these contributions cannot be provided here, but three examples of the uses of accelerator technology can be cited:

- HEP is the source of most of the accelerator innovations for three generations of synchrotron radiation sources. These important facilities are used by researchers in fields as diverse as environmental science, condensed matter research, and structural biology. The next generation of photon sources - free-electron lasers - will be based on the same accelerator technology as the linear e+e- collider that is the principal subject of this report.
- HEP has provided much of the technology used in the over 5000 medical linear electron accelerators that are used to treat 100,000 cancer patients every day. In addition, proton (and ion) cyclotrons and synchrotrons are being used increasingly to target precisely cancerous tumours.
- The development of high-quality superconducting cables, cryogenics, and ultra-high vacuum techniques for the powerful magnets that are used in HEP accelerators has led to important commercial applications, for example, in Magnetic Resonance Imaging (MRI) diagnostic instruments that are found in many large hospitals.

High-energy physics has been an intensive user, and a productive generator, of advanced computational technologies and methods. For example, the World Wide Web (WWW) was invented at CERN to allow sharing of the enormous amounts of data generated by HEP experiments. Today, particle physicists are among the leading developers of the "Grid": an innovative set of hardware and software tools and standards that will allow the rapid, dynamic linking of vast numbers of physically-separated computers into large re-configurable networks, allowing the sharing of data and, more importantly, the sharing of computational resources: memory, storage space, processing power and computer programs. Grid and other advanced information technologies (for example, innovative human-computer interfaces and visualisation tools) will make it increasingly possible for physicists to interact in real time with remote accelerators and particle detectors, and with their international collaborators as well. As in the case of the WWW, the benefits of the innovations created by physicists will extend to other scientific fields, to the private business sector, and to society in general. However, the full potential of these advances will only be achieved if the needed infrastructures (for example, high-throughput data networks) and protocols (data standards, security measures, etc.) are provided by governments and the private sector.

E. Outreach to Society and the Long-Term Vitality of the Field

The support of the public and its elected representatives is an essential requirement for ensuring the long-term vitality of any scientific field. High-energy physics deals with questions that are inherently fascinating, and the field has made a major contribution to the scientific dimensions of contemporary culture and consciousness, that is, to the public's understanding and appreciation of the nature of the physical world and mankind's place in the Universe. However, the concepts and methods of high-energy physics are necessarily esoteric and are often veiled in layers of scientific jargon. The results obtained by elementary particle physicists do not always have the immediate social impact or visual appeal of those obtained, for example, by biologists or astronomers. Thus, any long-term strategy for HEP must include public outreach and educational activities by scientists and scientific organisations, with the support and encouragement of the responsible agency officials.

Education is of special importance, since all branches of science must continually renew themselves by attracting and retaining talented young people. Elementary particle physics requires a strong commitment on the part of an aspiring scientist, given that the time needed to build an accelerator and detector, and to accumulate a sufficient amount of data for analysis, significantly exceeds the normally training time for a doctoral student. Clearly, the appeal of a career in high-energy physics can only be enhanced by the existence of a long-term strategy for the field, and reasonable expectation that energy-frontier facilities will continue to be built in the future.

Experience over several decades has shown that the field of high-energy physics is an ideal training ground for young scientists who, in later life, may find employment in the private sector, academia, or government service. Research at large accelerator-based facilities provides a challenging, highly competitive, multi-cultural working environment which promotes the development of useful and marketable skills such as the ability to work in teams, to plan and co-ordinate complex tasks, and to learn foreign languages.

IV. Road Map for the Future

A. Introduction

The Consultative Group's Road Map identifies the major scientific questions that are expected to define the frontiers of elementary particle physics during the next 20 to 30 years, and relates them to potential new major accelerator facilities. It provides a guide to the issues and options that governments will encounter as they develop their national high-energy physics strategies, and it will facilitate enhanced co-ordination and co-operation.

A world-wide consensus has emerged within the scientific community that a high-energy electron-positron linear collider is the next facility on the Road Map, and that a decision on its construction should be taken in the next few years. Moving even further into the future, the path to be followed will depend upon new discoveries and new technologies, and the Road Map will evolve to reflect these developments.

The Consultative Group believes that the most important goals of high-energy physics can be achieved within an overall funding envelope similar to that of the past 10 to 20 years. The scientific programme will be concentrated at a small number of large, unique, international accelerator-based facilities. As in the past, a country (or a group of countries) wishing to host such a facility will need to provide additional resources. It is likely, as has been the case in the past, that the establishment of new frontier facilities will be accompanied by the phasing out and decommissioning of older ones. This trend is illustrated in the chart that is appended to this report. It shows HEP accelerators since 1970. The solid bars indicate direct use for HEP, whereas shading denotes either use as injectors for the HEP accelerators of the next generation, or use for research with synchrotron radiation by a non-HEP community[3].

B. The Route to the Present Understanding

The Standard Model describes with great precision a wealth of experimental data, and its self-consistency can be used to constrain the parameters of the missing ingredients in the model (essentially the Higgs particle[4]) and to limit the parameters of extensions to the model, such as Supersymmetry. The data have come from an array of national and regional facilities, which include the following:

- Energy-frontier electron-positron colliders;
- Energy-frontier hadron colliders;
- Energy-frontier electron(positron)-proton colliders;
- Low- and medium-energy high-luminosity electron-positron colliders;
- Fixed target hadron and lepton experiments;
- Accelerator-derived neutrino beams.

Further information has been obtained from a wide variety of non-accelerator experiments (e.g., reactor-based neutrinos, electric dipole moments, the beta decay spectrum, double beta decay) including astroparticle physics (e.g., solar and atmospheric neutrinos, searches for "dark matter" candidates).

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[3] Sharing between HEP and other applications (e.g. synchrotron radiation, neutron production) is not shown.

[4] In modern elementary particle theory, any particle with non-zero mass (e.g., a quark) acquires it by interacting with the Higgs field. The Higgs particle is associated with that field, and thus its detection with the expected properties would constitute strong support for the Standard Model.

Data from these facilities have been used to develop the Standard Model and are in remarkable agreement with its predictions. A consistent interpretation of these data requires the existence of the Higgs particle with a mass of less than 200 GeV. Such a particle should be discovered at the CERN LHC, if it is not first discovered at the Fermilab Tevatron. These data also indicate that if the Higgs does *not* exist in this mass range, then some other detectable phenomenon must exist at higher energies, which produces the observed effects that are currently ascribed to the Higgs.

If the electro-weak and strong forces are to be made equal at an extremely high-energy scale ($\sim 10^{15}$GeV) there could be some new ingredient, different in character from the present components of the Standard Model, that may be accessible at lower energies. The most widely studied hypothesis is the existence of a new kind of matter, related to the current constituents of the Standard Model through a new kind of symmetry called Supersymmetry. According to this hypothesis, each of the known particles in the Standard Model has a "supersymmetric partner". The data indicate that the threshold for the production of these supersymmetric particles should be less than about 1 TeV, i.e., within the range of the LHC. An alternative proposal that would bring all the forces together at a very high-energy scale is that there are extra space dimensions (in addition to the familiar four space-time dimensions) which manifest themselves at an energy scale beyond that of current accelerators, but possibly within the reach of the LHC. Extra dimensions would be accompanied by the existence of new observable particles with masses in the LHC range. While the detection of these particles, or of a few low-lying supersymmetric particle states, at LHC would galvanise the scientific world, these discoveries alone would be insufficient to determine the precise form of the theory beyond the Standard Model. The relationship between the Higgs and the other particles will have to be measured to reach a detailed understanding of the underlying theory.

C. Elements of the Road Map

Recently, the scientific communities of Asia[5], Europe[6] and the United States[7] have projected the evolution of high-energy physics over the next twenty years or so. These independent, yet remarkably consistent, reports have been used in the construction of the Consultative Group's Road Map, and to identify the facilities needed to progress beyond the Standard Model.

There is world-wide agreement that the electron-positron linear collider with a center-of-mass energy of at least 400 GeV is the next facility on the world Road Map. The ACFA study confirms that *"the e^+e^- LC project is the next project for research in high-energy physics"* and recommends that "*the e^+e^- LC must start operation when the high-luminosity run of the LHC starts*". The ECFA study recommends "*the realisation … of a world-wide collaboration to construct a high-luminosity e^+e^- linear collider … as the next accelerator project* " and that *"an overlap time of operation of the LHC and that of the linear collider would be extremely fruitful"*. The HEPAP study recommends "*the highest priority of the US program be a high-energy, high-luminosity, electron-positron linear collider* " and clearly shows in their road map a considerable period of concurrent running of the LC and LHC.

There is also a strong world-wide consensus among scientists that the LHC proton collider and a linear collider are both essential to understand the physics of the Higgs and other phenomena that will be revealed at the scale of several hundred GeV to 1 TeV. For example, following the anticipated discovery of the Higgs at the LHC, the LC will be used to add

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[5] 2nd statement by ACFA on the Linear Collider, September 18th 2001, and the attached document of the statement. http://ccwww.kek.jp/acfa/document/2ndLC.html

[6] Report on the Working Group on the Future of Accelerator-Based Particle Physics in Europe, ECFA/01/213, September 2001. http://committees.web.cern.ch/Committees/ECFA/Welcome.html

[7] Report from the DOE/NSF HEPAP Sub-Panel on long-range planning for U.S. High-Energy Physics. http://doe-hep.hep.net/lrp_panel/

unique, precision measurements for establishing whether this particle is, in fact, responsible for the origin of mass and whether it has multiple partners as some theories predict. Similarly, if Supersymmetry is found, the two machines will play a complementary role in its discovery, with the LHC being a copious source of the supersymmetric partners of the quarks and gluons, and the LC ideal for producing the partners of the leptons. If the LHC discovers evidence for the existence of several new particles in a narrow mass interval, the LC will be able to disentangle them and measure their individual properties. Conceivably, the lowest mass supersymmetric particle, which would first be observed with the LHC, could be the one that constitutes the long-sought “dark matter”, i.e., the most abundant constituent of our Universe with a total mass greater than that of all visible galaxies. Obviously, a precise determination of the mass and other properties of this particle, using the LC, would be of major significance for cosmology and science in general. Given these arguments, the Consultative Group agrees that it is important for the LC and the LHC to have a significant period of concurrent operation, so that the discoveries and implications of the data from each of these machines can be used to great advantage in extracting and extending physics results from the other. The LHC will provide a broad, sweeping view of the TeV scale, and the LC, with its precision measurements, could point the way to new discoveries at still higher energies.

This tandem strategy has been used successfully several times already in developing the Standard Model. For example, data from proton accelerators and electron-positron colliders in the 1970’s allowed researchers to predict the masses of the W and Z particles sufficiently precisely that the SLC and LEP machines could be confidently designed and approved for the study of these particles *before* the experimental confirmation of their existence. Similarly, the precision data from SLC and LEP were used to predict the mass of the top quark before it was discovered at the Tevatron. Furthermore, it is the combination of data from SLC, LEP and the Tevatron that now points to the range of masses where the Higgs particle is expected to be found. The scientific goals requiring the concurrent operation of the LHC and the LC imply that the LC start operating before 2015. The results from the LHC and the LC will transform scientists’ understanding of the Standard Model and will illuminate the path to new physics. It is also possible, even likely, that there will be surprises that will lead into completely new directions.

It is too soon to be certain about which facilities will be required after the LHC and the LC. There are strong arguments emerging for a “neutrino factory” (see section V.D) to search for matter/antimatter asymmetry in the lepton sector, which would be a remarkable discovery with a profound effect upon both high-energy physics and cosmology. If Supersymmetry is confirmed, a higher energy lepton collider (operating in the multi-TeV energy range) may be required after the LHC and LC. There are two technologies being studied: a new type of electron-positron linear collider (CLIC) and a muon collider (although the technology for the latter is significantly less advanced). Alternatively, it may be that the physics beyond the Standard Model will indicate that a very large hadron collider (VLHC) operating in the 100 TeV centre-of-mass energy range, will be required to investigate the physics at even higher energy scales.

What is certain is that the results from the LHC and the LC, taken with the results from the other frontier machines (for example, the B-factories, high-intensity neutrino beams, and astroparticle physics experiments) will illuminate the physics at an energy scale much higher than can be reached by direct observation from either the LHC or the LC. Since new accelerator technology will be required to explore these higher-energy domains, it is vital that the current R&D into novel acceleration techniques be pursued at an adequate level.

In summary, the Road Map contains four interdependent strands:

i) Exploiting the current frontier facilities until the contribution from these machines is surpassed by the results from the LHC or LC;

ii) Completing and then fully exploiting the LHC;

iii) Preparing for the approval of a Linear Collider of at least 400 GeV centre of mass energy, to run concurrently with the LHC in the decade starting in 2010;

iv) Supporting an appropriate R&D programme into novel accelerator designs (for very high energy electron-positron linear colliders, neutrino factories, muon colliders and very high energy hadron colliders).

From this, it is clear that a decision is needed on the construction of a high-energy, high-luminosity electron-positron linear collider in the next few years, with concurrent support for advanced accelerator R&D. The cost of the LC is broadly comparable to that of the LHC, and can be accommodated if the historical pattern of expenditure on particle physics is maintained, taking into account the additional resources that the host country (or countries) will need to provide.

Two figures, appended to this report, illustrate the elements of the Road Map: one focussing on the roles of the LHC and linear collider at the energy frontier, the other depicting the roles of future facilities in the quark and lepton sector.

D. Conclusions

- The Consultative Group concurs with the world-wide consensus of the scientific community that a high-energy electron-positron linear collider is the next facility on the Road Map.
- There should be a significant period of concurrent running of the LHC and the LC, requiring the LC to start operating before 2015. Given the long lead times for decision-making and for construction, consultations among interested countries should begin at a suitably-chosen time in the near future.
- The cost of the LC will be broadly comparable to that of the LHC, and can be accommodated if the historical pattern of expenditure on particle physics is maintained, taking into account the additional resources that the host country (or countries) will need to provide.

V. International R&D Co-operation

A. Introduction

The advance of high-energy physics has been marked by remarkable progress in accelerator design and performance. In less than fifty years, and with approximately constant global funding levels (adjusted for inflation), the center-of-mass collision energies at the energy-frontier facilities have increased by three orders of magnitude[8]. Large accelerators have traditionally been built and operated by one country or region, though in most cases with intellectual contributions from other regions during design, commissioning and upgrading. This mutual help was organised within the network of the particle physics laboratories, which developed close relations, often since their foundation. There is a similar the long-standing tradition of international collaboration on particle detectors.

However, with the increasing cost and complexity of the accelerators it became clear that this model had to be modified. Thus HERA, which was constructed in the 80s in Europe, was the first accelerator built with significant hardware and manpower contributions from other regions. The first accelerator project with substantial contributions for R&D and construction from other regions is the LHC. These indispensable contributions come from Canada, India, Japan, Russia and the United States.

B. Electron-Positron Colliders

For electron-positron linear colliders, an Interlaboratory Collaboration (ILC) was initiated in 1993 with the endorsement of ICFA and ECFA to globally co-ordinate and share the R&D efforts. It has resulted in the co-ordinated exploration of different technologies and close collaboration to provide hardware for large-scale test facilities and their exploitation. Examples include: the Final Focus Test Beam Experiment (FFTB), the Accelerator Structure SETup test facility (ASSET) and the Next Linear Collider Test Accelerator (NLCTA) at SLAC; the Accelerator Test Facility (ATF) and the C- and X-band development at KEK; the TESLA Test Facility (TTF) at DESY, and the CLIC Test Facilities (CTF) at CERN. An intermediate assessment of the linear collider technologies was produced by an International Technical Review Committee (TRC) in 1995, commissioned by this Interlaboratory Collaboration. This review provided a solid basis for the continuation of the R&D effort and the promotion of a linear collider in the 500 GeV range by the different regions, where collaborations were formed to prepare more formally the JLC, NLC and TESLA projects.

The Technical Review Committee was reconvened at the request of ICFA in 2001 to assess the present technical status of the different technologies. It will establish, for each design, the R&D work that remains to be done to advance to more detailed technical designs, and it will comment on the potential of the designs to reach energies above 500 GeV in the center of mass, and on the R&D work needed to reach this potential. The appropriate interregional working groups have been formed, and the final report is expected in the second half of 2002.

During this assessment the R&D effort is continuing in the individual laboratories, concentrating on exploiting the test facilities and preparing more advanced ones, improving the engineering design (in particular of the radio frequency acceleration system), and optimising the subsystems for industrial production. The key challenges are: high-efficiency,

[8] From approximately 8 GeV at the CERN PS and Brookhaven AGS in the early 1960s, to 14 TEV at LHC.

high power radio frequency sources and distribution systems, accelerating sections with gradients that nearly a factor five higher than in existing linear accelerators, positron generation, and accelerator physics issues such as beam stability, alignment, and beam optics for tight focusing in the collision points.

Substantial progress has been made in the past with electron-positron storage rings operating at phi, tau, charm, and B0 energies, but significantly more luminosity will be needed in future. These upgrades, if authorised, will be incorporated into regional programmes. It should be noted that the results and insights gained from the experience with these small colliders (and from the studies conducted for their upgrades) are highly relevant to the development of the damping rings for future linear colliders, which will have to produce very small emittance beams. Given the extremely challenging performance requirements, close links have already been established between the groups working on colliders and damping rings.

C. Hadron Colliders

In parallel with the construction of the LHC, R&D for a future VLHC is being pursued, particularly in the United States, based in part on experience with LHC design and construction. The emphasis is on performance improvements of superconducting magnets and handling of high-current, high-energy proton beams. The findings will be important for a possible upgrading of the LHC luminosity and even for a potential energy upgrade of the LHC. The European, American, and Japanese teams are currently working closely together in connection with construction of the LHC; once that is achieved, they will be able to concentrate their efforts on advanced R&D.

Accelerator R&D for the hadron colliders will concentrate on the development of magnets that operate at higher magnetic fields and/or in higher radiation environments. Some of the most difficult challenges will be: developing new superconducting alloys with higher critical magnetic fields, controlling very-high power beams, and finding ways to absorb synchrotron radiation in a vacuum chamber that is held at liquid helium temperature. In addition, since civil engineering would be a major cost driver for a VLHC, novel tunnelling methodologies and technologies need to be developed.

D. Neutrino Beams

Theoretical studies and simulations have indicated that muon beams with reasonably high phase space density could be produced by high-intensity proton beams, combined with novel muon collection and beam cooling techniques. A “neutrino factory” could then be created by allowing the muons to decay in a storage ring. As a first step towards a neutrino factory, high-intensity neutrino beams could be produced using pions derived from multi-megawatt proton beams. Some R&D work is ongoing to develop the most critical technologies, but resources have been limited. The work is loosely co-ordinated by the laboratories involved and a formal framework for global collaboration has not been established.

E. Muon Colliders

A further development of the schemes described above could open the way for muon-muon colliders, using muons derived from high-intensity proton beams. Although the technological obstacles are formidable, this concept has the potential to reach energies beyond several TeV. At these very high energies, the synchrotron radiation that is produced when the beams collide precludes the use of electrons and positrons, whereas this radiation is much weaker in the case of muons.

F. Co-operation with Other Fields of Science

There are established, robust (albeit informal) links between the laboratories involved in R&D of accelerators for particle physics, and laboratories that develop advanced accelerators for other fields. For example, the work done for linear colliders is highly relevant for the next generation of synchrotron radiation sources based on free-electron lasers (FELs): the TESLA-FEL at DESY, the Linac Coherent Light Source (LCLS) at SLAC, and the SPring-8 Compact SASE Source (SCSS) at Harima. These proposed sources promise to open new vistas for chemistry, materials science, plasma physics, and biology, as did the previous generation of synchrotron-based sources derived from particle physics accelerator technology. The teams developing these novel sources are in close contact with (and often overlap) the linear collider design groups.

High-intensity proton beams being developed for neutron spallation sources (JHF in Japan, SNS in the United States, and the proposed ESS in Europe) are based on the experience with accelerators for particle physics research. These neutron sources are expected to contribute to the advancement of solid state physics, physical chemistry, material sciences, and biology. In turn, the proton sources required for future, advanced neutrino sources will greatly benefit from the technologies developed for the neutron spallation sources, and the operational experience obtained with them. Schemes for radioactive ion production for nuclear physics based on very high-intensity proton beams are under study for EURISOL in Europe and RIA in the United States. These beams are also important for accelerator-driven transmutation of nuclear waste, which is under active study in all regions. The teams working on these different accelerators are linked through advisory panels, as well as shared conferences and workshops.

G. R&D for New Concepts

While the R&D oriented towards medium-term projects as described so far is essential, these efforts are not sufficient to continue to extend the energy reach of accelerators in a longer term. New ideas are critically needed for acceleration, focusing and manipulation of charged particle beams for research in particle physics in the regime of 5 ~ 10 TeV or higher at the level of constituents. Although a small accelerator community is actively engaged in finding advanced technologies to address this requirement, it is clear that this field needs more human and material resources. Strong encouragement should be given to university groups to contribute in this area of research. For instance, opportunities should be created for stronger collaborations between the university groups and particle physics laboratories, with the latter providing the required infrastructure and technical expertise.

H. Conclusions

- The long-standing productive ties between the HEP laboratories provide a sound basis for establishing, as needed, formal collaborations for targeted and effective R&D for selecting the technologies and conceptual designs, and for jointly working out the detailed technical specifications of global-scale projects. Such a need currently exists for the e+e- linear collider that is to be realised through global collaboration.
- To ensure the long-term vitality of particle physics as described by the Road Map, a diverse accelerator R&D programme should be maintained. Innovative accelerator concepts should be explored well before they may be needed, since the lead times for large, complex new projects span decades, and the unpredictable course of discovery in physics may shift the currently foreseen priorities of the facilities on the Road Map.

VI. Organisational and Managerial Issues Associated with Creating a Major New International High-Energy Physics Facility

A. Introduction

This section describes the findings and conclusions of the Consultative Group regarding the administrative and management (i.e., non-scientific, non-technological) aspects of future global-scale co-operation on large HEP facilities. The principal goal is to enumerate and analyse the relevant generic issues and options, without being prescriptive or limiting in any way future discussions about a specific collaborative project. The details of any final arrangements will have to be decided during the course of project-specific discussions and negotiations among the international partners. A preview of the matters that will have to be the subject of these negotiations should be of significant value for government officials (who will be directly involved), for proponents of host country initiatives (who will want to make their bids as attractive as possible to potential international partners) and to concerned members of the scientific community (who will want to understand the timescales and complexities associated with international negotiations).

The Consultative Group noted that past instances of establishing large international scientific projects (in high-energy physics and in other domains) show that inter-governmental consultations and negotiations are lengthy and complex. The issues on which agreement has to be reached (many of which are listed in this section of the report) lie within the sphere of competence of national administrations and are, to a large extent, independent of, and complementary to, the scientific and technological goals and parameters of the project. Sufficient time is needed for appropriate discussions at national, regional, and international levels. Therefore, in contemplating any large new accelerator-based facility, it is important to allow sufficient time for inter-governmental consultations, well before any financial, time, or other commitments are expected. These discussions complement the scientific and technological discussions in the scientific community.

While trying not to be too specific, the Consultative Group did consider the hypothetical case of a next-generation electron-positron linear collider facility, because it is the next large accelerator-based facility that is being sought by the high-energy physics community. In the remainder of this section, however, the future collaboration is referred to as the “Project”: a large, global-scale, inherently international undertaking, consisting of an accelerator and one or more detectors.

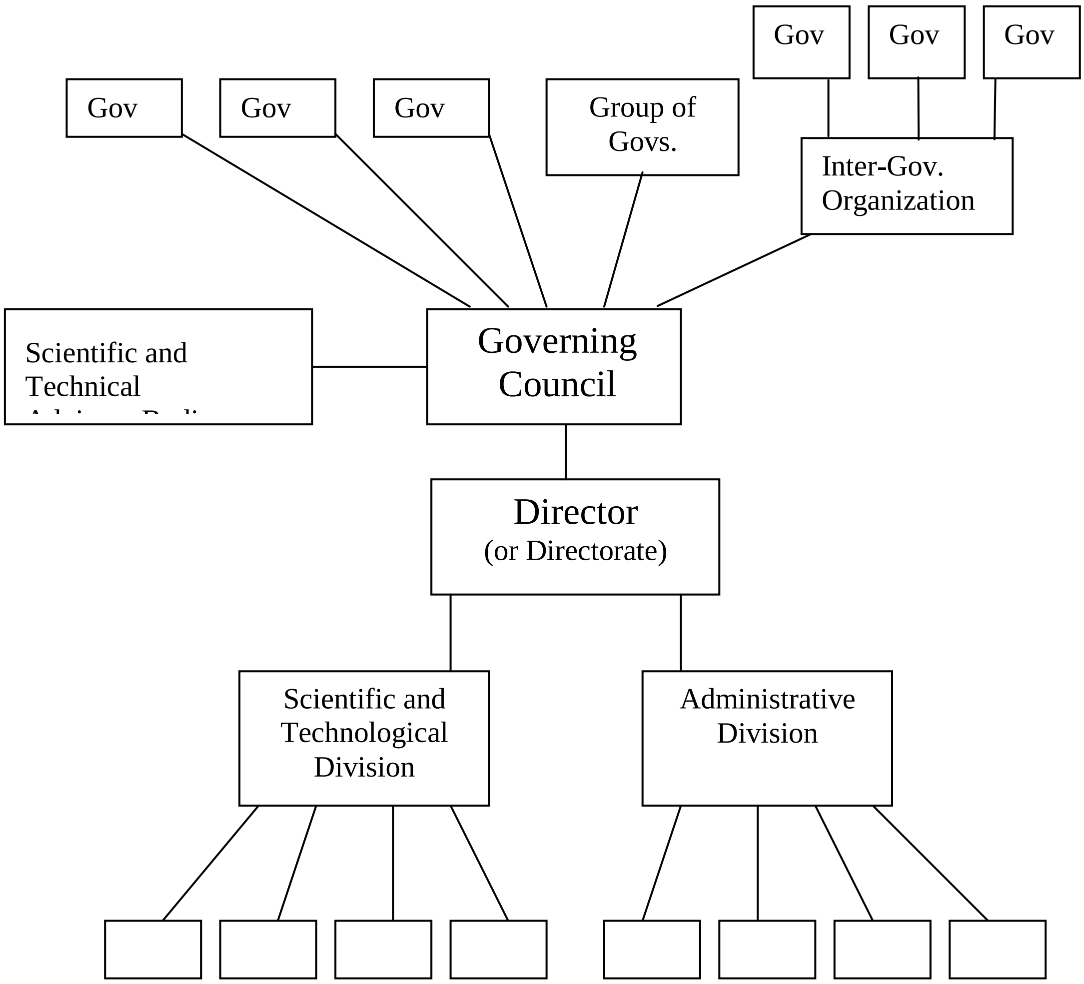
B. Legal Basis of the Project

The collaboration will require large contributions (mostly in-kind, but also in personnel and in cash) from several countries. To ensure its success and stability, to maximise national commitments, and to safeguard their investments, the partners will require that the project be based on a government-level agreement or agreements. The agreement(s) should establish the project for a limited period of time (e.g., 25 or 30 years), with provisions for extension and potential upgrading, as well as for dismantling and disposal of hardware. The establishing documents will have to clearly define and describe the objectives and scope of the undertaking (i.e., to design, build and operate a large international project) but it may be desirable to subdivide the activity into two or more phases (for example, design, construction and operation) thus allowing interested countries to work together prior to making major financial commitments, and before site-selection and other important decisions are made.

Smaller countries, smaller contributors, or countries within a specific region may choose to group in a joint membership. Others may act through intergovernmental or international organisations (e.g., CERN). The mode of participation will be a national decision, but collaborator groupings will be desirable for achieving a streamlined and efficient organisational structure. Each participating Government may designate one or more agencies or laboratories to serve as its operating agent

C. Management

The management structure of the Project will have to be defined in the primary intergovernmental agreement, following detailed negotiations. A notional example of the management topology of the project is shown below.



The organisation should be designed so that all participants consider themselves integral parts of the common project, with a strong stake in its success, and appropriate influence on its decision-making processes and the selection of members of its various bodies. The structure should be robust, with clear lines of authority and responsibility, covering technical and administrative aspects of the project activities, and include the relationship to the host laboratory (see section D below).

It is envisioned that there will be a body (a "Council") representing the governments' funding agencies (advised by the national and international scientific community). The Project Director/Directorate and other senior managers should have the power to make difficult choices and decisions within the scope of their authority, while reporting regularly to the Council and seeking its approval when necessary. The international partners will not, however, want to create a large new international administration, and will want the personnel of their national laboratories to play important roles in the Project. The correct balance between the above requirements will have to be established through detailed negotiations.

The legal standing of the Project will have to be precisely defined. It seems likely that it will have to have a legal identity in the host country, allowing it to hold funds, issue calls for tender, and enter into procurement, employment, insurance and other contracts. This may not be necessary if the host laboratory takes on all or most of these responsibilities. Several possible types of arrangements were considered by the Consultative Group, including a new international organisation, and a limited liability company according to national law. The voting procedures of the Council, including effective minority protection, have to be defined[9]. Also, there has to be agreement on how the financial contributions to the project are reflected in the decision-making process.

If the participants agree that the GAN concept applies, it would be incorporated as an integral part of the project development. When and to what extent that is done should be determined based on close examinations of GAN's technical and managerial impacts. In particular, given the decentralised character of a GAN, the management authorities and responsibilities of the personnel at local and remote sites need to be clearly defined.

D. Special Role of Host Laboratory / Host Country

The Project will require a broad range of infrastructure services besides the design, construction, and operation of the accelerator facility, including: personnel and property protection, environmental safety, security, financial services, personnel administration, site and facility management, transport, guest services, and technical infrastructure such as workshops, stores, experimental support, computing, and operators for the accelerator and subsystems. In addition, particularly during the construction stage of the project, there will be a need for facilities for component check-out, and temporary storage. Since the existing major high-energy physics laboratories in the world have extensive knowledge and experience in these areas, as well as physical infrastructures (buildings, roads, machine shops, vehicles, etc.) they can offer substantial assistance. Thus it is strongly preferred that the project be closely linked to an existing laboratory or laboratories so as to make maximum use of the latter's infrastructure. The linkage referred to here is primarily organisational; whether the major new facility is built on the site of the host laboratory would depend on specific circumstances.

It is likely that the Project will become the host laboratory's most important (or perhaps only) activity, and thus the laboratory organisational and management structures might have to undergo significant reconfiguring. The services to be provided by the host laboratory might be considered to be in-kind contributions to the project. The formal arrangement for such services, the cost apportionment for various phases of the project, and the interface with respect to the project management will need to be defined and agreed between the Project and the host laboratory.

E. Key Personnel

Key personnel may be identified in the project management, in the host laboratory, and in the national laboratories and universities that participate in the project. It may be necessary to strengthen the labour force on the Project site by seconding personnel to the project management. The participating laboratories may be asked to make available some of their expertise on a priority basis to ad-hoc needs of the project. The commitment to do so should be specified in the international agreement. Key personnel should be selected by the Project and its bodies (e.g., Council). Seconded personnel should be selected by the delegating institution, subject to approval by the receiving partner. Given that several categories of

[9] The rules governing ESRF/Grenoble with a balance of number and weight of votes may be a useful illustration.

personnel will be involved (employees of the Project itself, of the host laboratory, seconded personnel from other laboratories, personnel associated with the detector(s), visitors, etc.) it will be necessary to clearly define beforehand the lines of authority and responsibility.

F. General Personnel Provisions

Issues that will require careful and detailed consideration will include remuneration and social security (insurance, retirement, etc.), residence and working permits for expatriate and seconded staff, matters affecting spouses and children (work permits, school), health insurance and general benefits, expatriation allowances, etc. Problems can be reduced if seconded staff retain their home system benefits (social security, insurance). However, differences in working conditions, and, in particular, different salary levels (as well as working hours, holidays, etc.) of Project staff, host laboratory staff, and long-term secondees might impede their mixing in teams. It has to be decided whether the personnel employed directly by the Project should reflect a balanced representation of the participating countries, and whether staff positions should be open to citizens of non-participating countries. Staff seconded to remote project teams in the GAN context are expected to be under the supervision of the Project management, while remaining staff members of their home facility.

G. Financial Provisions

The Project will require contributions in-kind, in seconded personnel, and in cash from all participating countries. While the objective will be to keep cash requirements to a minimum, a common fund will have to be established. The management of this fund will be the responsibility of designated Project personnel, but the total size, the formula for setting the contributions, and the process for disbursement will have to be agreed between the participants. In principle, the in-kind contributions will be preferred by participants, but it will be necessary to achieve a fair distribution of high- and low-tech contributions among all the collaborating partners. It is nominally anticipated that the contributor will be responsible for his in-kind contribution for the lifetime of the project, including spares, maintenance, upgrading and decommissioning. However, some components may be treated in an alternate manner. For example, components that are expected to have a lifetime significantly shorter than the overall project (e.g., some components of the accelerating system) may require treatment as an operating expendable beyond the initial complement. The method of financing accelerator operating costs (utilities, personnel, etc.) will have to be agreed among the participants.

The international partners will have to agree on an accounting procedure for in-kind contributions, incorporating the differing accounting practices in participating countries, so that an equitable measure of relative contributions can be made. This may require some sort of unified reporting/accounting system within the collaboration.

If the Project is established as a legal entity, it will be the legal owner of the fixed and floating assets of the collaboration, including all in-kind contributions, and it will be responsible for import and customs issues, and the disposal of the equipment after decommissioning.

H. Procurement Practices

The central management of the project will have to contract for services, and purchase common items. These contract placements and purchase orders should be organised in the most open and unrestricted way possible, thereby allowing the project to benefit from the greatest possible flexibility and cost savings. It is understood that national/international tendering rules will be recognised where required. Special attention will have to be paid to the issue of customs (fees, regulations) and taxes (including VAT and import excise taxes).

I. Accelerator - Detector(s) Interface

The governments that invest in the Project have a legitimate and vital interest in a detector (or several detectors) working at the time of the accelerator commissioning. It is likely, however, that the number of countries participating in the detector collaboration will greatly exceed the number financing the accelerator. Thus there must be adequate assurance that the organisation responsible for the collider has sufficient participation in and influence over the detector construction. Similarly, the detector collaboration must have a way to convey its special considerations which may impact construction and operation of the accelerator.

In addition, the interface between the detector collaboration and both the host laboratory and the Project must be carefully designed. It may be that the detector collaboration will need to have its own international managerial and organisational structure, although on a smaller scale than that of the accelerator. The obligations of each of the three partners must be clearly defined to minimise grey areas which could lead to later difficulties. Hence, the basic infrastructure to be provided to the detector collaboration must be settled. This includes office space, workshops, design support, stores, general computing facilities, administrative help (procurement, financial accounting for the common fund), guest houses, etc. The specific civil engineering work and basic infrastructure (cooling and ventilation, electricity, overhead cranes, etc.) for the detector(s), which is traditionally included in the collider project, must also be covered.

The detector collaboration will, however, have to look after the infrastructure of the detector proper and possibly after special laboratories and clean rooms which may be required. Moreover, the general computing capacity of the host laboratory may need to be augmented by the institutions collaborating in the detector construction and operation.

Another problem to be addressed at an early stage is that of possible participation of the detector collaboration in the operating costs of the collider, particularly those countries who have not contributed to the collider construction. It should be noted, however, that the well-established practice in HEP is for facilities to provide beams to users free of charge.

J. Further Topics

Intellectual Property: The collaboration may claim appropriate intellectual property rights available within applicable national jurisdictions over any device, technology or software tool that is developed while carrying out the work program. Intellectual property rights, whether patented or not, generated in the frame of the collaboration by project staff and/or participating teams or individuals should be available for the purposes of the project free of charge throughout the duration of the project.

Liability: The project-partners should hold each other liable only for gross negligence and wilful injury. Seconded staff and project staff working on the host site will be subject to the local rules and regulations and be under the authority of the host laboratory's management.

Accession of New Participants to the Accelerator Collaboration: The agreement among the members of the accelerator collaboration should contain provisions for allowing additional participants to join the effort after the original international agreement is signed. These provisions should be such that they encourage new membership in the collaboration where the prospective participant can make a meaningful contribution to the accelerator project.

Additional topics that are likely to be needed in an agreement but were not examined include (not listed in the order of priority) but are not limited to:

- Disputes
- Sharing of operating costs

- Identification and membership of special committees and technical panels
- Withdrawing from the Project
- Future upgrades
- Non-member access to data
- Process of amending the agreement
- Decommissioning
- Disposition of assets

K. Initiating International Negotiations

The Consultative Group examined the process for initiating negotiations for the international agreement, with special attention to the question of who takes the lead, and whether a prior decision on the technical approach is required. No conclusions were reached by the Consultative Group, but two generic models were discussed:

Model 1: A competition among nationally-led efforts, followed by negotiation with international partners

In this model, a small number of countries each decide to lead an independent effort to design a new facility, with the understanding that the future site will be in the lead country, and that certain technology choices will be preferred (e.g., room-temperature vs. superconducting accelerating cavities). These efforts proceed in parallel and may involve international partners for design and R&D. Some of the parallel efforts may even collaborate on selected aspects of design. After each design is mature, and reliable cost and timeline estimates have been made, the government of each lead country may decide to offer to host the future international facility while providing a substantial fraction of construction and/or operating funds. Each government will then seek to attract international partners for its host site and technical design. This competition will continue until a consensus lead country project emerges (a "winner"). Negotiations then take place with interested partners to define the exact terms (financial and others) of the international collaboration.

Model 2: An international consensus on the design of the accelerator and the collaboration, followed by a competition among potential hosts.

In this model, all interested countries engage in a structured exploration of alternative designs for a next-generation accelerator, on a site-independent basis. A minimal administrative/funding arrangement may be needed to allow joint R&D projects. Following a full exploration of all viable options, a process is put in place to choose one final site-independent consensus design. Presumably, extensive consultations with the scientific community take place. The defined elements of the final chosen design include: operating parameters (energy, luminosity, etc.), principal technology choices, as well as mature cost and time estimates for construction and operation. Participating countries tacitly agree to abide by the final decision. Interested countries then discuss and agree on the desiderata for an international collaboration. Following agreement on the technical and management aspects of the collaboration, a small number of interested countries (possibly acting in groups) develop offers to host the facility. Each host candidate seeks to attract international partners, until a "winner" emerges. Final negotiations then take place to finalise the terms of the agreement and the rights and obligations of all international partners.

L. Conclusions

- Preparing and negotiating a formal agreement (or a series of agreements) for the design, construction and operation of a facility on the scale of a linear collider is very time-consuming. Past experiences (in high-energy physics and in other domains) show that several years may have to be devoted to consultations and negotiations that are the responsibility of governments. Such a process is, to a large extent, independent of, and complementary to, the scientific discussions that are needed to establish the scientific and technological goals and parameters of the project. Therefore, it is important to allow sufficient time for inter-governmental consultations, well before any financial, manpower, timeline, or other commitments are made.

- For a large collider project, the generic criteria for, and contents of, the agreement(s) between international partners have been enumerated by the Consultative Group: legal basis of the project, management structure, special role of the host laboratory/host country, personnel provisions, financial arrangements, procurement practices, accelerator-detector interface, intellectual property, liability, accession of new participants, and others. Within each category, issues and options can be identified now, but the actual details of a final agreement cannot be foreseen at this time, since they will emerge in the course of inter-governmental negotiations based on the negotiating positions of the participating governments.

- A critical but still unresolved issue is the method for initiating the negotiating process for a linear collider. There currently exist several competing design approaches, and the scientific communities of at least three countries have expressed interest in hosting the facility. Current process to establish the ITER fusion project and the ALMA telescope array may provide valuable insights on how to proceed with a global high-energy physics facility, both with respect to the negotiating phase, and the subsequent facility construction, operation and management.

- While the work leading to this report was carried out under the aegis of the OECD, participation in a global high-energy physics facility such as the linear collider should be open to any government with an interest and capability to participate.

Appendix: The Consultative Group: Process and Membership

Since 1992, the OECD Global Science Forum (formerly the Megascience Forum) has been a venue for meetings of senior science policy officials. Its goal is to identify and maximise opportunities for international co-operation in basic scientific research. The Forum meets twice each year, and establishes special-purpose working groups and workshops to perform technical analyses, and to develop findings and recommendations for actions by governments. These groups bring together government officials, scientific experts, and representatives of international organisations. The Consultative Group on High-Energy Physics was established in June 2000, based on a proposal from the delegations of the United Kingdom and the United States. The United Kingdom, which was designated as the lead country, appointed Dr. Ian Corbett as Chairman. He was supported by a Bureau whose members were Dr. Simon Peter Rosen (United States), Dr. Hermann-Friedrich Wagner (Germany) and Prof. Sakue Yamada (Japan). Four meetings of the Consultative Group were held: in November 2000 (at the DESY laboratory in Hamburg, Germany), June 2001 (at CERN in Switzerland), November 2001 (in Tsukuba, Japan) and in February 2002 (at the SLAC laboratory in the U.S.).

The composition of national delegations was at the discretion of the participating countries. Typically, delegations were headed by senior programme managers, and included other administrators as well as one or more prominent scientists. The number of delegations from OECD[10] and non-OECD[11] countries were as follows: 1st meeting: 19/2, 2nd meeting: 19/1, 3rd meeting: 12/0, 4th meeting: 12/2. Three subgroups met separately to compile and analyse information for consideration by the Consultative Group as follows: (1) to examine organisational issues related to creation of a global collaboration to design, construct and operate an accelerator-based facility (Chair: Dr. Harold Jaffe, United States); (2) to explore managerial issues related to the actual design, construction and operation of the facility by the collaboration (Chair: Dr. Helmut Krech, Germany); and (3) an annotated "Road Map" of a 30 year + projection of major facilities likely to be sought by the world high-energy physics community (Chair: Prof. Ken Peach, United Kingdom). The first two subgroups met jointly.

The Consultative Group focussed on the international science policy issues that are relevant to the future of high-energy physics; scientific and technical issues were discussed only as they related to the Group's main focus. In order to base their findings on the best information, and to ensure openness and transparency, the Consultative Group invited representatives of the following organisations to present the results of their work, and to fully participate in the deliberations on an equal footing with the national delegations[12]: the International Committee for Future Accelerators (ICFA), the Asian Committee for Future Accelerators (ACFA), and the European Committee for Future Accelerators (ECFA). The Consultative Group also included a delegation from CERN.

Members of the OECD secretariat attended all of the meetings. They provided organisational and editorial assistance.

The following table lists the delegates who attended two or more of the four meetings. In addition, the Directors of the laboratories where the meetings took place participated in the discussions as hosts.

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[10] Including the European Commission

[11] Delegations from the Russian Federation and the Peoples's Republic of China attended some, but not all, of the Consultative Group meetings.

[12] The Chairman of the High-Energy Physics Advisory Panel (HEPAP) was a member of the United States delegation.

Members of the Consultative Group on High Energy Physics

ACFA	Prof. Setsuya Kawabata Prof. Sachio Komamiya
Australia	Prof. Geoffrey Taylor
Austria	Prof. Dr. Walter Majerotto
Belgium	Prof. Jean Sacton
Canada	Dr. Richard Keeler Dr. Nigel Lloyd
CERN	Dr. Kurt Hübner
China	Dr. Hesheng Chen
Denmark	Dr. John Renner Hansen
ECFA	Prof. Lorenzo Foa
European Commission	Mr. Stephen Davies
Finland	Prof. Dan-Olof Riska
France	Dr. Joël Feltesse Dr. Denis Perret Gallix Dr. Guy Wormser
Germany	Dr. Rolf Dieter Heuer Dr. Hermann-Friedrich Wagner
ICFA	Dr. Roy Rubenstein
Italy	Dr. Umberto Dosselli
Japan	Mr. Yoshitaka Koike Mr. Hiroyuki Seki Dr. Nobu Toge Prof. Sakue Yamada
Korea	Prof. Sunkun Oh Dr. Jungil Lee Prof. Dong-Chul Son
Netherlands	Dr. Jan Bezemer
Norway	Dr. Leif Westgaard
Russian Federation	Prof. Mikhail Danilov
Spain	Prof. Antonio Ferrer
Sweden	Dr. Lars Gidefeldt
Switzerland	Dr. Jean-Pierre Ruder Dr. Monique Werlen
United Kingdom	Dr. Ian Francis Corbett (Chairman) Prof. Brian Foster Prof. Ken Peach Dr. Frances Saunders
United States	Prof. Frederick Gilman Dr. Harold Jaffe Dr. John R. O'Fallon Dr. Simon Peter Rosen
OECD	Dr. Stefan Michalowski Mr. Kenji Sudo

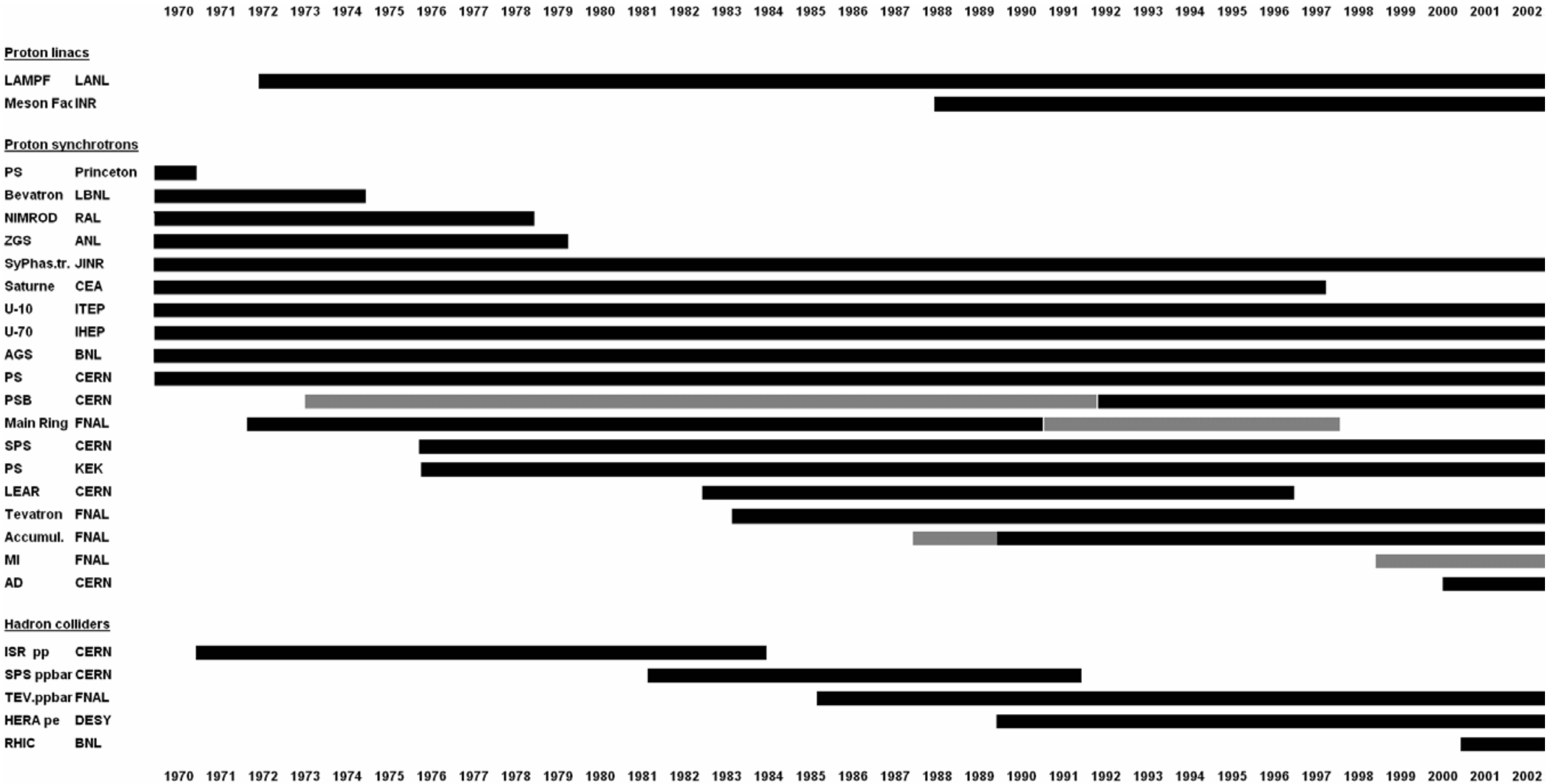


Chart showing the history of proton linacs, proton synchrotrons, and hadron colliders from 1970 to the present. The solid bars indicate direct use for HEP, whereas shading denotes either use as injectors for the HEP accelerators of the next generation, or use for research with synchrotron radiation by a non-HEP community

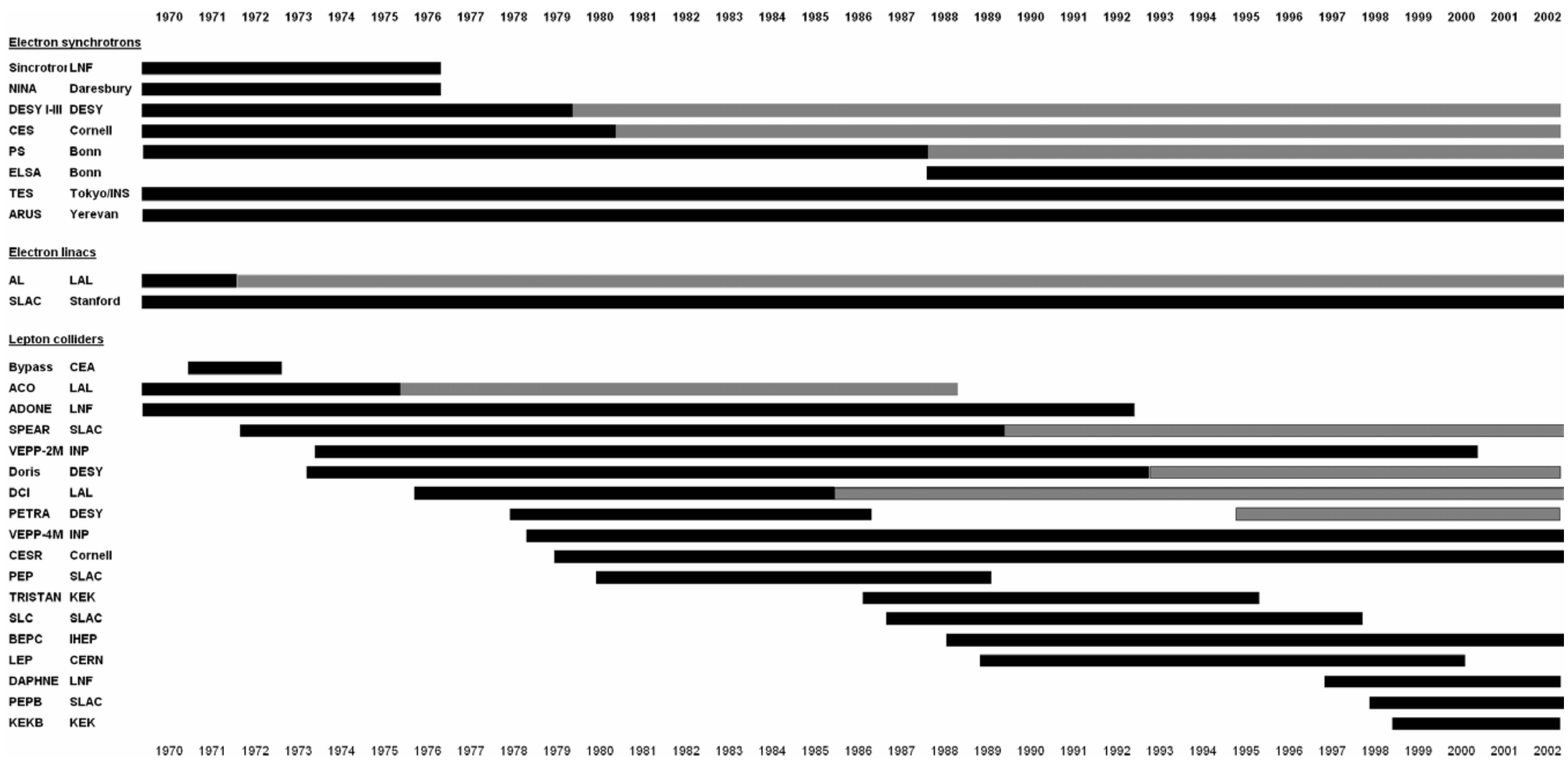
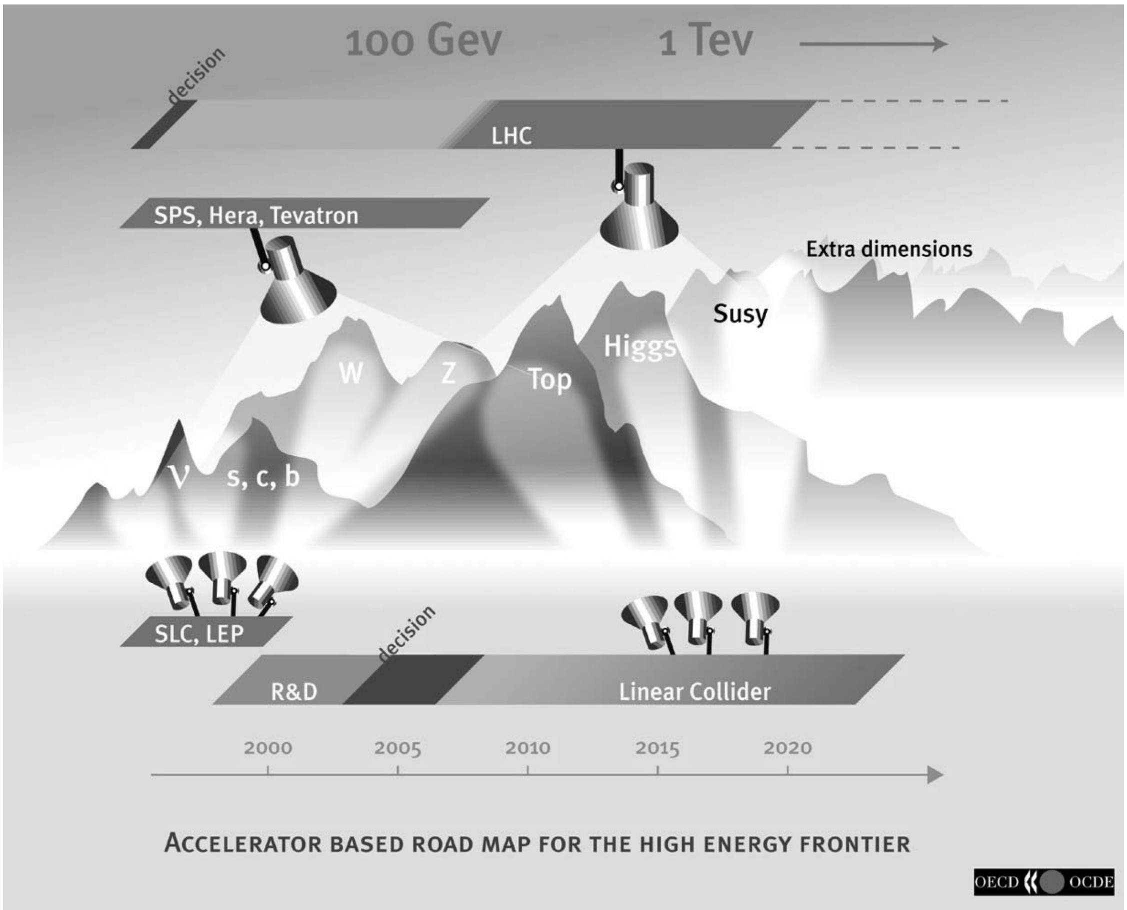


Chart showing the history of electron linacs, electron synchrotrons, and lepton colliders from 1970 to the present.

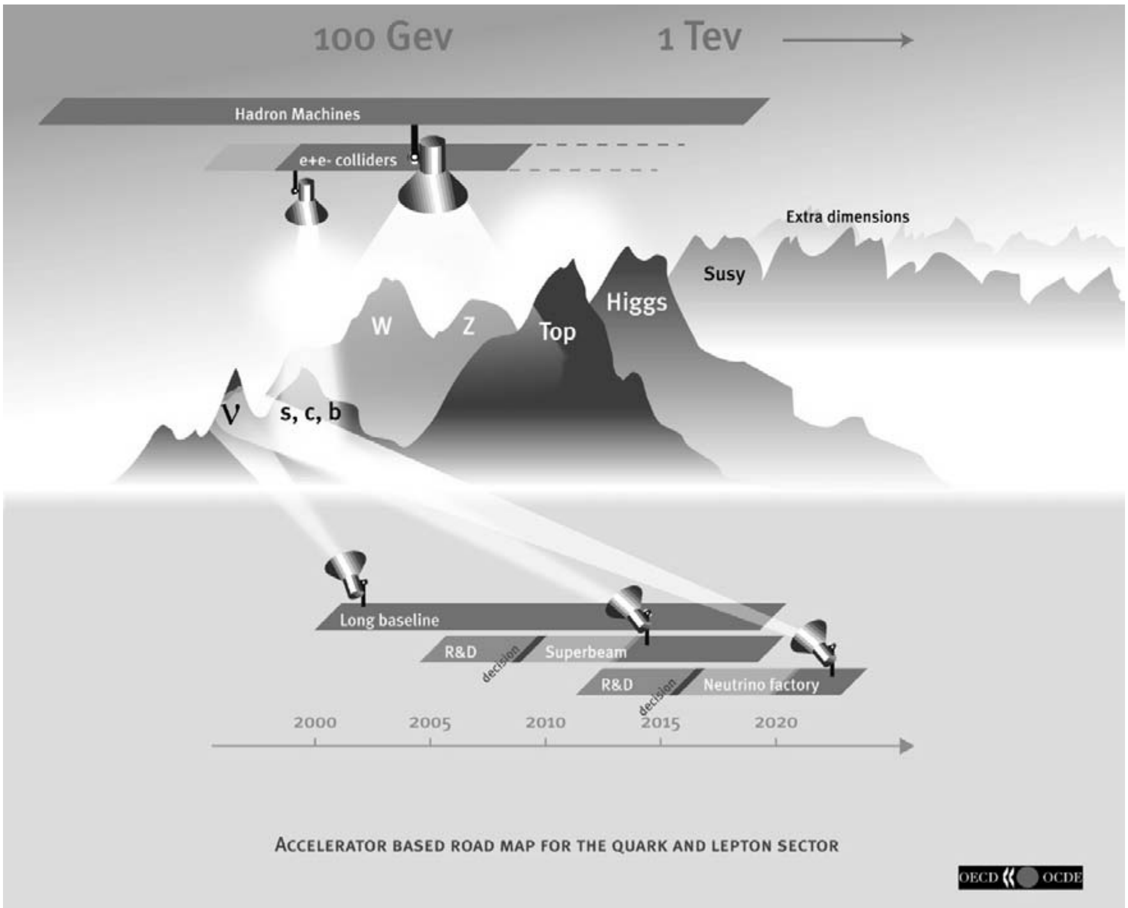


Accelerator-based road map for the high energy frontier.

Existing and future accelerator-based energy frontier facilities are shown illuminating a physics landscape with known and hypothesized features. A time axis is shown at the bottom, while the energy scale of the principal physics phenomena is indicated at the top.

For each facility, the time sequence of its various phases is indicated: R&D (orange), decision and negotiation (red), construction (yellow), operation (dark orange).

The complementary nature of hadron and e+e- colliders is illustrated. The former allow the exploration of large physical domains. The latter are able to focus selectively on key topics which, in turn, sheds light on the entire landscape.



Accelerator-based road map for the quark and lepton sector.

Existing and future accelerator-based facilities are shown illuminating the quark and lepton sector of a physics landscape with known and hypothesized features. A time axis is shown at the bottom, while the energy scale of the principal physics phenomena is indicated at the top.

For each facility, the time sequence of its various phases is indicated: R&D (orange), decision (red), construction (yellow), operation (dark orange).

The complementary nature of the various facilities is illustrated: some allowing the exploration of large physical domains, others being used to focus selectively on key topics, thus shedding light on the entire landscape.