WORLD-WIDE PERSPECTIVES IN ACCELERATORS AND THE ROLE OF CERN

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Abstract

A brief overview of the large accelerator-based facilities in operation and under construction is given. The proposals and ideas for the next steps are outlined with emphasis on elementary particle physics. Approaches to organize these next steps are discussed, and the possible role of CERN is presented.

PRESENT LARGE ACCELERATOR – BASED FACILITIES

The large facilities in operation and under construction are based on an amazing development of techniques and technology. The key breakthroughs and developments are listed in Table 1. Some are the bright ideas of individuals; others are the result of a perseverant effort of many groups supported by the large laboratories working in friendly competition.

Table 1: Key breakthroughs

Linear accelerators (Wideröe 1927)
Cyclotron (Lawrence 1931)
Colliding beams (Kerst, O'Neill 1956)
Altern. gradient (Courant, Livingston, Snyder 1952)
Linear e+e- collider (Tigner 1965)
Electron cooling (Budker 1966)
Stochastic cooling (van der Meer 1972)
Superconducting magnets (BNL, CERN, DAPNIA, DESY, FNAL, RAL since 70's)
Superconducting cavities (CERN, CEBAF, Cornell, DESY, FZK, KEK since 70's)

The progress based on these ideas has not only resulted in fine instruments for particle physics but also provided appreciated tools for physics at large, science, medicine and industry. Prominent examples relevant for particle physics, for general physics and science are briefly enumerated below.

Elementary Particle Physics

Table 2 gives the large proton synchrotrons in operation and under construction including their neutrino beam lines as these are often in itself substantial facilities. The proton energy and the average neutrino energy are indicated. The accelerators in the Russian Federation are listed under Europe.

J-PARC at Tokai/Japan will start operation in 2007 sending a muon neutrino beam to the Superkamiokande detector as is being done by the KEK/PS. The Main Injector (MI) at FNAL will provide a muon neutrino beam to the MINOS experiment from 2005 onwards, the SPS at CERN to OPERA from 2006. Note the impressive length of the baselines, i.e. distances to the far-detectors, given in parenthesis.

Table 2: Proton Synchrotrons and their neutrino beams

Americas	Asia	Europe
In operation		
BNL/AGS 28 GeV FNAL/MI[a]) 120 GeV FNAL/Booster[b]) 8 GeV	KEK/PS[c]) 12 GeV	IHEP/U70 70 GeV CERN/PS 24 GeV CERN/SPS[e]) 400 GeV
Under construction		
	KEK-JAERI/ J-PARC[d]) 50 GeV	
Neutrino beams in operation		
FNAL/Mini-BooNE[b]) 1 GeV (0.45 km)	KEK/K2K[c]) 1.3 GeV (250 km)	
Neutrino beams under construction		
FNAL/ NuMI[a]) 3.5 GeV (730 km)	KEK-JAERI/ OA2[d]) 0.7 GeV (295 km)	CERN/CNGS[e]) 18 GeV (730 km)

Table 3 lists the colliders in operation and under construction and gives their centre-of-mass energy. It can be seen that the most powerful colliders are operating in America but that no large accelerators are under construction

Nuclear Physics

Large accelerators are in operation in about 20 laboratories for nuclear physics. More performing accelerators will become available for this field: It has recently been decided to upgrade the electron beam energy of CEBAF from 6 to 12 GeV, LHC and J-PARC under construction also have a strong programme for nuclear physics. In addition, a new radioactive beam facility (RIBF) is under construction at RIKEN in Japan.

General Physics and Science

One of the major spin-offs of particle physics are the synchrotron radiation sources. More than 50 special electron storage rings are in operation to produce radiation spanning from infrared to x-rays for a large number of fields as medicine, biology, chemistry, materials science and many branches of physics.

Table 3: Colliders and their centre-of-mass energy

Particles	Americas	Asia	Europe
In operation			
e+e-	SLAC/PEPII 11 GeV Cornell/ CESR-c ≤ 6 GeV	KEK/ KEKB 11 GeV	LNF/DAΦNE 1 GeV BINP/VEPP4 12 GeV
ep			DESY/HERA 314 GeV
$p\bar{p}$	FNAL/ Tevatron 2TeV		
ion-ion	BNL/RHIC Au-Au 39 TeV		
Under construction			
e+e-		IHEP/ BEPCII ≤ 5 GeV	BINP/ VEPP2000 1.8 GeV BINP/ VEPP-5 ≤ 5 GeV
pp			CERN/ LHC 14 TeV
ion-ion			CERN/ LHC Pb-Pb 1148 TeV

As an example, Table 4 gives user facilities offering third-generation light sources in operation and under construction. These sources provide radiation with peak brilliance (photons per s.mrad^2.mm^2.0.1%) up to 10^{25} and a time-averaged brilliance up to 10^{21}**.**

Table 4: Third-generation light sources

Americas	Asia	Europe
In operation		
APS ALS CAMD LNLS NSLS SSRL	KEK/PF NSRL NSSRC PLS Spring-8 SSRF UVSOR	BESSY II DORIS II ELETTRA ESRF SLS SRS
Under construction		
CLS	Boomerang BEPC-II SESAME	ALBA DLS MAX III SOLEIL

Eleven fourth-generation light sources (free-electron lasers) are already in operation, three are under construction (SLAC/LCLS, RIKEN/SCSS, DESY/TTF-VUV). They constitute the next step in the development of radiation sources. For example, radiation of fs duration at a wavelength of 0.15 to 1.5 nm with a peak brilliance up to 10^{33} and an average brilliance up to $3x10^{22}$ will be produced by LCLS driven by a 5 to 14 GeV SLAC electron beam .

Another spin-off of the accelerators developed for particle physics are the neutron spallation sources driven by powerful proton accelerators. These sources serve a large user community in physics, chemistry, materials science, geology, engineering and biology. Table 5 gives the user facilities, kinetic energy of the protons and the beam power at the target. ISIS, LANSCE and PSI are operating; SNS and J-PARC are under construction becoming available in 2006 and 2007, respectively.

Table 5: Neutron spallation sources

Americas	Asia	Europe
LANSCE 0.8GeV, 1 MW SNS 1GeV, 1.4 MW	J-PARC 50 GeV, 1 MW	ISIS 0.8GeV, 0.2 MW PSI 0.6GeV, 1.4 MW

POSSIBLE NEXT LARGE FACILITIES

Elementary Particle Physics

A number of conceptual studies have been conducted to understand the feasibility of possible future accelerators and their physics reach. Table 6 provides a synopsis of the possible next steps.

Table 6: Possible next facilities for particle physics

hadrons	RHIC luminosity upgrade LHC luminosity (energy) upgrade VLHC 40, 200 TeV (phase I, II)
e+e-	Upgrade B-Factories Linear collider with 0.5 to 1. TeV Multi-TeV linear collider with 3 (5?) TeV
ν-beams	ν_μ Superbeam (π and K decay) ν_μ ν_e Neutrino Factory (μ-decay in ring) ν_e Neutrino Factory (β-decay in ring)

Consider first hadron colliders. Since it is logical and in the good tradition of particle physics to fully exploit an investment, studies have been made on the possible upgrade of RHIC and LHC to increase their luminosity. The essential new feature of RHIC would be the insertion of electron cooling to reduce the luminosity decay resulting from beam loss and beam blow-up. It would increase the average luminosity by a factor ten [1]. An upgrade of the luminosity of LHC by a factor up to ten in steps has been studied including its consequences for the detectors. This could be done combining measures such as increasing the crossing angle, the number of particles per bunch, and eventually the number of bunches plus a stronger focusing in the interaction points by means of stronger quadrupoles. The study includes also considerations of an energy upgrade from 7 to 12.5 TeV per beam replacing all 8 T dipoles with dipoles of 15 T [2]. The more ambitious and certainly more rewarding step towards higher energies in hadron colliders would be VLHC which could be implemented in two phases: the first phase storage ring based on super-ferric magnets and providing collisions at 40 TeV centre-of-mass energy; the second based on superconducting magnets and reaching 200 TeV in the centre-of-mass with the first phase ring serving as injector. Both would be housed in the same tunnel of about 230 km circumference [3].

After decommissioning of LEP at the end of 2000, B-Factories are leading in the field of electron-positron collisions with record performances and peak luminosities above 10^{34} per cm^2 s^1. Studies have been made indicating that an increase of luminosity by more than a factor 10 seems to be feasible [4]. However, the main interest and R&D has been concentrated on an e+e- linear collider with a centre-of-mass energy of 0.5 TeV upgradeable to 1TeV which would effectively complement LHC. A number of collaborations have presented detailed designs either based on 1.3 GHz superconducting cavities [5] or on accelerating structures operating at 11 GHz and ambient temperature [6] with luminosities up to $3x10^{34}$ per cm^2 s^1 at 0.5 TeV. In parallel, R&D for a multi-TeV e+e- collider is actively pursued [7].

After the exciting results from the large underground neutrino detectors which seem to indicate phenomena beyond the Standard Model of particle physics, a strong interest in more powerful neutrino beams from accelerators has motivated a number of studies [8]. Three types of facilities have been considered: a ν_μ “Superbeam”, a more powerful version of the present ν_μ beams, stemming from decays of π and K which are generated by a proton beam providing about 4 MW on the target whereas present proton drivers produce only up to 0.5 MW ; a “Neutrino Factory” producing simultaneously a copious beam of ν_μ and ν_e which result from muons decaying in a suitable storage ring ; an intense ν_e beam, a so-called “Beta-Beam”, could also be generated by beta-emitting radioactive ions decaying in a storage ring.

Nuclear Physics

For the medium term, upgrades of the GSI, REX-ISOLDE and TRIUMF are under discussion. Proposals for new large facilities have been worked in detail and put forward: FAIR at GSI [9], RIA by ANL [10], SPES at LNL [11] and SPIRAL 2 at GANIL [12]. These facilities will offer substantially improved beams. For example, compared to the present GSI, FAIR will provide an intensity increase of up to a factor 100 for primary heavy ion beams, and a factor 10’000 for secondary radioactive beams. In the long term, a facility like EURISOL [13] could provide even more intense radioactive beams using a proton driver of about 4 MW. Studies have been conducted to understand how this facility could be combined with a neutrino factory. It is obvious that the research programme at these new facilities will have a large overlap with elementary particle physics.

General Physics and Science

A number of new facilities have been proposed for general physics and other fields of science. The following examples are limited to Europe.

New third generation synchrotron light sources have been studied and proposed: PETRA II at DESY and MAX IV at Lund. Fourth-generations light sources (FEL) are under consideration for the production of soft x-rays (FEL at BESSY II and 4GLS at Daresbury) or hard x-rays (SPARX in Italy and TESLA X-FEL).

A study for a next-generation neutron spallation source (ESS) has been conducted in Europe assuming a 1.33 GeV proton driver providing 5 MW on each of the two targets, but the project has not been pursued.

Accelerator-driven transmutation is investigated by ENEA and INFN in Italy in the framework of TRASCO. It would require a very demanding proton linac providing a 1 GeV beam and a beam power of 30 MW.

ORGANISATION OF THE NEXT STEPS IN PARTICLE PHYSICS

In the years 2000 to 2001 the particle physics communities in Asia [14], the USA [15] and in Europe [16] reflected on priorities for the next step and established a consensus that the next large facility should be a e+e- linear collider with a centre-of-mass energy of 0.5 TeV to be built soon so that its operation would overlap with LHC.

International Initiatives

These regional initiatives entailed a number of activities on the international level. The OECD Global Science Forum (GSF) established a Consultative Working Group on High-Energy Physics in which physicists and representatives of funding agencies participated in order to reflect on priorities and possible approaches to organize the next steps on a global basis. The report suggested the following priorities: i) exploitation of current frontier facilities; ii) completion and full exploitation of the LHC; iii) preparing for the development of a next-generation electron-positron collider; and iv) the continued support for appropriate R&D into novel accelerator designs [17]. This report was endorsed in the GSF Ministerial Meeting in January 2004.

The International Committee for Future Accelerators (ICFA) welcomed the OECD statement and reaffirmed in February 2004 “its conviction that the highest priority for a new machine for particle physics is a linear electron-positron collider with an initial energy of 500 GeV, extendible up to about 1 TeV, with a significant period of concurrent running with the LHC”. ICFA has set up previously the International Linear Collider Technical Review Committee which issued a report on recommended accelerator R&D for the e+e- linear collider [18], and the International Linear Collider Steering Committee (ILCSC). The latter, in turn, set up the International Technology Recommendation Panel (ITRP) which is supposed to recommend by mid-summer 2004 the preferred rf technology for the next linear collider studies, i.e. either superconducting cavities or copper structures operating at ambient temperature [19]. After this choice a Global Design Initiative is planned, a sort of global proto-collaboration with a central team and three regional teams, in order to advance towards a Conceptual Linear Collider Design Report.

European Initiatives

The European Committee for Future Accelerators (ECFA) had set up a Working Group on the Future of Accelerator-Based Particle Physics which concluded that the European priorities are LHC, on-going experiments, and, the "construction of a high-luminosity e+e- collider with an energy range up to at least 400 GeV as the next accelerator project", continued accelerator R&D aimed at a neutrino factory, a multi-TeV e+e- linear collider and VLHC [16]. In 2002, emulating the other regions, ECFA set up a European Linear Collider Steering Group with subgroups in accelerator science, physics and detectors, and organisational matters. The latter Subgroup reflected on how such a global project could be organized with emphasis on the European perspective and the possible role of CERN. It has submitted its report to ECFA [20].

The European Union is launching the 6^{th} Framework Programme (FP6) for the period 2003 to 2006[21]. It offers a unique opportunity to apply for funding in order to develop a coherent European accelerator R&D programme for Particle Physics. For this reason and given the ECFA recommendations, a European Steering Group on Accelerator R&D (ESGARD) has been set up by the directors of CCLRC, CERN, DAPNIA/CEA, DESY, LNF, IN2P3, and PSI in order "to develop a proposal to optimize and enhance the outcome of the Research and Technical Development in the field of accelerator physics in Europe aimed at preparing and conducting a coherent set of bids to apply for EU funding in the 6th Framework Programme. "

The relevant sub-programme in FP6 is called Structuring the EU Research Area/Support for Research Infrastructures and has a budget of 655 M€. The latter is again divided in 5 sub-programmes: Mainly two of them, Integrated Activities (IA) and Design Studies (DS), are of interest for ESGARD.

The IA is aimed at provision of infrastructure related services to the European Research community and contains Networking Activities (NA) and Joint Research Activities (JRA). NA provides support for pooling of resources for meetings, workshops, special training, travel, manpower for web and databases; JRA is focused on developing high performance and innovative techniques to improve the services provided by existing infrastructure.

The Design Study Programmes are aimed at facilitating the development of concepts, prototyping and testing for future European or world-wide relevant facilities.

FP6 supports also R&D for Nuclear Physics, Synchrotron Radiation and Transmutation.

The CARE project of ESGARD, approved in 2003, is participating in IA. In its NA part, CARE is coordinating studies and technical R&D for

- Electron linacs and colliders
- Beams for European neutrino experiments
- High-energy and high-intensity hadron beams

In its JRA part CARE is developing

- Superconducting (sc) rf technology
- Photo-injectors
- High-intensity proton beams
- High-field sc magnets and cables.

The first DS bid of ESGARD, EUROTEV, was submitted in 2004 and covers a design study of subsystems common to all designs of a Global TeV Linear Collider; the formal approval is expected in summer 2004. In preparation are bids for design studies for

- Neutrino Factory based on μ-decay ring
- Next generation Φ-Factory
- LHC luminosity upgrade

which possibly will be submitted in 2006.

Note that the Neutrino Factory based on β-decay is within the EURISOL DS, submitted in 2004 by the Nuclear Physics Community

POSITION OF CERN

After an in-depth review of resources, commitments, and desiderata of the particle physics community, the CERN management proposed the following priorities for 2004 to 2010 which has been endorsed by the CERN Council:

- LHC completion and start of operation in summer 2007
- Consolidation of the LHC injector complex
- Europe-wide coordinated accelerator R&D
    - LHC luminosity upgrade (primary goal)
    - Generic Linear Collider design issues
    - Good contact with EURISOL and FAIR
- Possible new fixed-target experiments to be defined in a workshop in September 2004
- Decision for minimal investment based on these studies in 2006 (proton linac 4, R&D, fixed-target experiment)
- Accelerate tests of CLIC concept to understand feasibility by 2010 with voluntary, external contributions under common responsibility.

In order to define the strategy for the next decade, a review is planned in 2009-2010 taking into account the results of LHC and the developments on the international level and in the other regions.

REMARKS

Future large facilities are complex and expensive. Obviously, each region cannot afford all types of facilities and get them in a timely manner due to limited resources.

Hence, the burden has to be shared globally. Two concepts have been considered for the future organisation of such large facilities: i) the foundation of a common global laboratory with equitably shared, mainly in-kind contributions from the regions; ii) the concept of a strong lead country or region with again mainly in-kind contributions from the other regions, possibly complete subsystems.

The first concept has been proposed by ICFA for the future linear collider laboratory, the second concept has been successfully tested with e.g. HERA and LHC. In the first concept many equal partners would work together similar to the large collaborations constructing and operating particle physics experiments but in this case without a strong coordinating institution in the background. The second concept would imply that a large part of the required resources would be covered by the host. Although the difficulty is in finding such a host, it has the advantage of limiting the sensitivity of the project to external contributions which are sometimes difficult to control. Each region would drive a project which optimally uses its existing resources (investment, human resources, and competences) and existing forms of organisation. This approach would substantially ease the setting up of the new facilities and should not be discarded, as it might be more realistic and might have more chances of success.

The second concept in particular would make a global coordination of large-scale scientific facilities very desirable, at least amongst the major players. This coordination would favour the complementary aspect of the future facilities and avoid excessive competition as the latter risks redundancy and rash decisions.

A good example of such a long-term coordination is the Twenty-Year Outlook for future scientific facilities prepared by the Office of Science of DOE in the USA [22].

A similar exercise could be initiated on a global basis though the body for such global coordination does not yet exist. Maybe the OECD Global Science Forum would be a possible forum to start the discussion given that it provides contacts at highest level between a large set of leading countries and has already conducted studies on cooperation in various scientific fields.

CONCLUSIONS

Accelerator-based science is important and thriving. It is based on a large park of highly-performing, specialized accelerators and a closely-knit network of motivated, innovative accelerator engineers and physicists. Future accelerators need continued innovation in technology and accelerator physics. Vigorous R&D with strong international coordination, cooperation and communication is imperative. This is well promoted by EPAC'04.

ACKNOWLEDGEMENTS

Discussions with J.P.Delahaye, G.Guignard, A. Hofmann, and in particular K. Hübner, have been very helpful and their contribution is gratefully acknowledged.

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