INTERNATIONAL COLLABORATION WITH HIGH ENERGY ACCELERATORS

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Abstract

On the occasion of this first International Conference on Particle Accelerators the status and perspectives of international collaborations on high-energy accelerators are reviewed. Historically, accelerators were mainly built under the responsibility of a single laboratory while the detectors for experiments were frequently built by collaborations of many institutes. During the last few decades many accelerators were also built with contributions from outside laboratories. This paper reviews the aspects of international collaboration on accelerators using a few examples to illustrate the various aspects, advantages and challenges of such collaborations.

INTRODUCTION

IPAC 2010 is the first in a new conference series that will combine the success of three predecessor conferences in America, Asia and Europe on a common platform of global character. This series will enhance the international scientific exchange and dissemination of knowledge in the field. Joining forces is the appropriate way to address the challenges of projects which become larger, more complex and expensive, and which have increasing life times. The International Committee for Future Accelerators (ICFA) proposed in 2006 to combine PAC, APAC and EPAC. This was agreed by the three conference organizations. My thanks as former chair of ICFA therefore go to these organizations for having agreed to the IPAC format, and to our Japanese colleagues who offered to host this first conference.

ICFA and Accelerators

The mission of ICFA is to facilitate the international collaboration on accelerators for particle physics covering all project phases, from the proposal to operation. ICFA works through panels, three of which deal directly with accelerator issues: the Beam Dynamics Panel; the Panel on Advanced and Novel Accelerators; and the International Linear Collider Steering Group.

In 1993 ICFA has classified the different organisational models for the construction and operation of particle physics accelerators and experiments:

- National or regional facilities
- 'Larger' facilities which cannot be funded by one country or region
- Very large projects needing a collaboration of several countries with comparable shares of the total construction and operation cost
- Very large projects in the frame of an international organisation

This talk will focus on the experience gained with the last three models.

WHY COLLABORATE INTERNATIONALLY

For many years already, experimental particle physicists form collaborations, to cope with size, complexity, and cost of their experiments. They are united in a common scientific approach and share the responsibility for building and operating their complex detectors and for analysing the data. These collaborations have grown with the energy of the accelerators, by about a factor 6 every ten years. In addition they became more and more international. This growth was handled successfully by applying the lessons learned during one step to the next one. Nevertheless, doing science in very large collaborations remains a challenge.

A number of similar reasons have led also to more international collaboration in the construction of large accelerators:

- The size and cost of projects increased and the necessary funding could no longer be borne by one country.
- The scientific challenges related to the development of new acceleration technologies called for pooling the world-wide know-how.
- The political climate concerning basic research has changed. Basic research is seen as something one should tackle in international collaboration, as no immediate financial return is expected and the risk is shared.
- The time gap between new projects increases as projects become bigger. Therefore laboratories are faced with the problem of providing interesting work for their highly skilled staff, an incentive to engage also in outside projects.

There are also challenges related with this approach:

- A world-wide coordination of accelerator related R&D work needs to be organised.
- A scientific consensus concerning the performance parameters has to be reached.
- In certain cases a choice of the most adequate accelerator technology needs to be made.
- The potential conflict between priorities (laboratory versus outside project priorities) needs to be dealt with. For obvious reasons the management of a laboratory tends to give higher priority to in-house projects.
- The question of responsibility and management control becomes more complicated.

In case of very large experiments and detectors these challenges have been met successfully in the past. Can the detector model be applied to accelerator projects?

MODES AND PHASES OF COLLABORATIONS

Collaborations on detectors have four phases:

- Research and Development on questions of detection methods as well as detector technologies most appropriate to meet the scientific needs
- Design and construction of a common detector, where the responsibility for each individual sub-detector lies with a sub-set of the collaboration. Each such group carries the full responsibility (design, construction, funding) for its component. The overall coordination of the construction is typically in the hands of the host laboratory.
- Maintenance and operation of detectors remains with the groups which were responsible for the construction. The same is true for upgrades and improvements.
- The analysis of data is done by individuals and coordinated according to scientific questions.

Collaborations on accelerators have in principle similar phases:

- Research and Development of accelerator technologies
- Design and construction of new facilities
- Maintenance and operation of facilities which were built in a collaborative effort
- Analysis of the performance and development of improvement programmes.

Several examples of international collaborations will be discussed with these aspects in mind. It will become clear that the first two phases have worked very well in the past, while the last two phases so far have not been implemented except in a few small-scale tests.

EXAMPLES OF INTERNATIONAL COLLABORATIONS

HERA

HERA, an electron/positron – proton collider was built between 1986 and 1991 at DESY in Hamburg and operated between 1992 and 2007. About 25 % of construction funds were provided by international partners (through in-kind contributions, including manpower). Ten countries from Asia, North America and Europe contributed components such as RF systems, magnet measurements and controls, superconducting dipoles, quadrupoles and correction magnets, and beam dumps. Two countries (China and Poland) contributed mainly through manpower performing work on various machine components.

This way to build an accelerator became known as the 'HERA-Model'. The success was a result of the direct cooperation between DESY and the partner laboratories and institutes. Partners were responsible to get necessary funding in their countries. Early links during the development phase, continuing during construction phases between producers and the responsible DESY experts were another important element. The measurements and quality control of all components was done at DESY. Accounting used an artificial unit – the "HERA-Mark", corresponding to 'value-costing'. Possible cost overruns were at the risk of the producing laboratory. The institutes were fully involved in the planning and construction of HERA as well as in the advisory bodies of DESY. Their involvement during the operation phase would have been desirable. The cost of operation was carried by Germany.

Large Hadron Collider

The LHC is a proton-proton collider constructed in the LEP tunnel with first collisions in 2009. The LHC is designed to reach a centre-of-mass energy of 14 TeV. The machine and the first operation experience are described in detail at this conference [1].

The Large Hadron Collider attracted significant contributions from several major nations outside the CERN member state community, making it truly a world machine. The external contribution to the LHC machine from Canada, India, Japan, Russia and the USA corresponded to about 12% of the total project cost. About half was in cash and half in-kind. France and Switzerland as host countries made special contributions.

A few examples illustrate the in-kind components: Canada contributed to the LHC itself (twin-aperture quadrupole magnets for "beam cleaning") and to the injector chain in order to achieve higher beam brightness. The main Indian hardware contribution were superconducting sextupoles, amounting to half of this kind of magnets. In addition, India supplied the LHC magnet support jacks. Japan provided much of the basic material (steel and superconducting cable), quadrupoles to squeeze the colliding beams, and compressors for cooling superfluid helium. The largest part of the Russian contribution were the magnets for the beamlines linking the SPS synchrotron to the LHC and insertion magnets. The hardware contributed by US laboratories included superconducting quadrupoles and their cryostats for beam intersections, superconducting dipoles for beam separation and cryogenic feed boxes. This complex collaboration was successful as the impressive start of luminosity operation illustrates.

The international collaboration through "in kind contribution" worked well for LHC, also for components where the performance is critical for the operation (interaction region magnets). Weak points were that there was no global optimization and that maintenance and spare components were not included in the agreements.

TESLA Test Facility and FLASH

The TESLA Test Facility (TTF) at DESY was an early building block in a world-wide effort to advance linear accelerators based on superconducting RF technology (SCRF). The R&D programme for high-performance superconducting accelerators was launched at DESY in 1992 in the framework of the TESLA Collaboration, involving more than 50 institutions. The initial focus was an 500 GeV e+e- Linear Collider, but soon an X-ray free electron laser was integrated. This led to the TESLA project and a Technical Design Report (2001).

Although the project was not approved as proposed, it had at least four off-springs: The TESLA Collaboration became the TESLA Technology Collaboration (TTC), coordinating and advancing the SCRF in international collaboration; FLASH, a soft X-ray FEL user facility at DESY, using the linear accelerator of TTF as backbone; the European XFEL, based on the TESLA technology; and the International Linear Collider Global Design Effort (ILC-GDE).

SCRF structures for accelerators were developed in many countries for quite some time already. A major performance break-through was achieved when the combined world expertise in the SCRF technology became focused in the TESLA Collaboration. In this way the operational field gradient per meter was increased from below 10 MV/m to above 30 MV/m while the cost per meter was reduced fourfold, making the technology feasible for large scale production. Overall, a more than 25-fold improvement in performance/cost was reached in 10 years. The work continues today within the ILC-GDE and TTC.

The TTF linac was built as an integrated systems test to demonstrate that a linear collider based on SC cavities can be built and operated with high reliability. Many components were in-kind contributions provided (and paid for) by the international partners. The outside contributions corresponded to about 25% of the project cost.

In 2004 TTF became a user facility for experiments using soft X-rays. Renamed FLASH, it today contains 7 accelerator modules and is routinely in operation. FLASH is a pilot facility for practically all aspects of an XFEL (accelerator technology, beam physics, FEL process, user operation) of an XFEL and many aspects of the ILC (high bunch number and bunch current).

TTF also became a test bed for remote operation which might be an interesting mode of operation for future globally built accelerators. Although there was never a genuine remote control room, remote operation by experts became a standard feature during commissioning and machine shifts. Experts can control parts of the linac from home and no longer need to travel. Also during the more recent runs with high beam-loading, collaboration members participated remotely, took and analysed data.

The European X-ray Free Electron Laser

The European X-ray Free Electron Laser is being built in the framework of an independent Limited Liability Company, located in Hamburg. DESY will play a key role in the construction and operation of the accelerator as well as in detector development, scientific use and general infrastructure support.

The accelerator complex consists of 100 accelerator modules, containing 800 1.3 GHz cavities of 23.6 MV/m gradient plus 25 RF stations. The complex is built by a consortium of 17 institutes from 9 countries. About 62 % of the accelerator cost is carried by Germany, 38 % by the other countries.

The accelerator module is a good example of shared responsibilities: Cryostats are built by Italy, China, Spain and France; SCRF cavities by Germany and Italy; the RF power coupler contributed by Germany and France; the super-ferric magnets by Germany and Spain; the beam position monitors by Germany, France and Switzerland; and the frequency tuners by Germany and Italy. The cryo-modules will be assembled in France and shipped to DESY for testing and installation.

Many of the partners have already collaborated on TTF, creating a basis of understanding and trust necessary to realise such a complex project. At the technical level the collaborations works very well and as one team. A major construction project, however, faces constraints which differ from the R&D phase. These constraints are linked to a difference in willingness of the partners to deal with risks, escalation - all related to the financial aspects of the project. Here a strong host laboratory is helpful and can re-assign contributions, provided it can cope with its own budget constraints.

Therefore being a host for a major international project puts substantial constraints on the infrastructure support. Here a model used for detectors might be a long-term solution, the establishing of a Common Fund to which all participating countries contribute and which is spent for commonly used items like infrastructure or serves as risk budget. However, so far partners prefer in-kind contributions and try to minimize cash contributions.

TOWARDS A GLOBAL PROJECT

International Linear Collider

The International Linear Collider (ILC) is the most ambitious truly global project in particle physics so far. In order to advance the understanding of the innermost structure of matter and the early development of the universe, several thousand particle physicists and accelerator scientists around the world, during the past 15-20 years, have coordinated their work on developing the technologies necessary to make a Linear Collider feasible and understanding its scientific potential.

The ILC is a 500 GeV centre of mass energy e+e- linear collider, upgradeable to ~1 TeV. It is considered as the next energy-frontier machine complementing the LHC, scientifically supported by a common road map. It is designed and developed by equal partners, which in itself is an experiment of its own. The coordination of the work lies in the hands of the Global Design Effort (GDE) team working without a 'host laboratory'.

Over 20 years of active international R&D at NLC/JLC based on Cu X-band technology (12 GHz), at the CLIC two-beam accelerator (30 GHz), and with the TESLA Superconducting RF (SCRF, 1.3GHz) laid the foundation for a credible concept.

ICFA and the ILC

The ILC has been a global project even before the technology was chosen. Therefore ICFA played a much stronger role in the ILC than in any other project of particle physics so far and has been helping guide the international cooperation on the Linear Collider since the mid 1990's.

Major early steps were taken in 1995 with the first Technical Review Committee (TRC) Report and in 1999 through an ICFA Statement on Linear Collider. In 2002 ICFA commissioned the second TRC Report and in 2004 unanimously endorsed the technology recommendation of the International Technology Review Panel.

To provide this guidance, ICFA set up the International Linear Collider Steering Group (ILCSC) in 2002. The primary role of the Steering Committee is to promote the construction of an Electron-Positron Linear Collider through world-wide collaboration. The ILCSC engages in defining the science case, the scope and primary parameters for machine and detector, monitors the machine R&D activities and makes recommendations on the coordination and sharing of R&D tasks as appropriate, identifies models of the organizational structure adequate for constructing the LC facility, and engages in outreach. Together with representatives of the Funding Agencies it provides the oversight over the Global Design Effort.

In 2002 the German Ministry for Education and Science took a decision to fund the construction of a European XFEL and encouraged DESY to continue its work on the Linear Collider as an international project. In 2004 the "International Technology Recommendation Panel (ITRP)" conclusion was endorsed by ICFA. In 2005 ICFA appointed a director for the Global Design Effort (GDE) and the regions (Asia, Europe and the North America) nominated their regional directors.

The Global Design Effort

Since 2005 the GDE has defined the baseline design (2005), completed the conceptual design with a cost estimate (including first iteration cost reduction) (2006), and written a Reference Design Report (RDR) (2007). In 2008 the GDE restructured for Technical Design Phase, envisaging the final planning for the TDR in 2010. The GDE will produce an ILC Project Proposal by 2012.

The work is structured in four blocks: R&D for technical risk mitigation, cost constraints, global mass production models and industrialization, and a project implementation plan. The R&D work is based at test beam facilities in Japan, US, and Europe. The cost constraints deal with improving the gradients in SC cavities, a reduction of the underground civil construction cost, system integration, and optimizing the overhead. The global mass production focuses mostly on the components of the SC linac, the project implementation plan, and sharing of the mass production.

The GDE as global effort with regionally balanced teams has successfully coordinated high-gradient SCRF work across the regions [2]. This includes the build-up of the corresponding technology know-how in industry.

CLIC

Recently the work of the GDE has been linked to the linear collider development at CERN. Since the late 1980ies CERN has been engaged in a normal-conducting technology aiming at the multi-TeV energy range, based on a two-beam acceleration scheme, employing a drive beam for RF power production, CLIC. CLIC is also another model for international collaboration on accelerators. The CLIC/CTF3 collaboration is organized as a Physics Detector Collaboration with Memoranda of Understanding describing specific contribution and resources. The members are full responsibility for work packages and providing corresponding resources. 20 CERN member states participate with additional voluntary contributions and 16 institutes from China, India, Japan, Pakistan, Russia, Turkey, Ukraine, and the USA. Further new members are under discussion. At present the main focus is the use of the CLIC Test Facility 3 to address all major CLIC technology issues, such as the drive beam generation, the RF power production, the two-beam acceleration scheme, alignment and to test the acceleration structures. A report about the status of CTF3 is given at this conference [3]. The link between the GDE and CLIC will create synergies in some design areas and help compare the different approaches.

Facets and future of the ILC as global project

Summarising the many facets of the international collaboration of a Linear Collider one sees steady, but slow progress.

It is clear today that an approval of a linear collider will be strongly linked to the results provided by the LHC. Assuming that these results confirm and strengthen the science case of a linear collider, the GDE has also launched a discussion about the approval process, on international governance, site selection, and funding models, in order to ease and speed up the approval process.

LESSONS LEARNED

Accelerators in the past were mainly built by one laboratory, but increasingly with considerable contributions from other partners. Some examples were given above, but there are many more which have profited enormously from international contributions. Other examples are the Next Linear Collider and Final Focus Test Beam at SLAC or the French injector contribution to LEP. The selection was made on the basis of my own knowledge. The experience made in all these projects resembles the one presented above.

One can conclude the following:

- R&D collaborations work well and are highly productive
- The construction of new accelerators as collaborative effort similar to those on detectors works but remains

a challenge from a financial point of view, due to conflicts arising from a preference for in-kind over cash contributions, especially as a cost-effective management needs to control the budget centrally.
- Partners who have contributed to the construction so far do not engage in the maintenance and operation of the facility they built. This remains a major challenge for global projects.

The Global Design Effort is the first attempt to perform major R&D work on a future accelerator without a specific host laboratory. Therefore GDE is in itself an experiment in how future global HEP projects could be organized. After 5 years of existence one can identify the advantages and disadvantages of such an approach.

Advantages are: recognition by funding agencies as a truly Global Project; independence from a single (traditional) accelerator laboratory; robustness against local financial crises; level playing field for future host sites; and quality of collaborators.

Disadvantages are: no (or little) direct control over funding; reliance on laboratory/institutes 'good will' for support; no centrally located team ('virtual' laboratory); exposure to possible conflicts between laboratory priorities and global project priorities.

It is worth looking more closely at what could be done to overcome the hurdles. The hurdles which need to be overcome are related with a long term engagement by each partner in a project which most likely is not located in the own laboratory.

One could imagine as a model a world-wide collaboration of accelerator laboratories and institutes, working together with the goal to build, operate, utilise and upgrade a new large accelerator facility, following the example of major detector collaborations in particle physics. All scientists and engineers would form a network to integrate their scientific and technical knowledge, ideas and resources, and focus them on a common project - a merger of worldwide competence. In addition, the participating institutes would build and operate regional projects at home while being actively engaged in a common project elsewhere.

Partners would contribute through components or subsystems and share the responsibility. The facility would be the common property of the participating countries. All participants would demonstrate a visible level of activity, thus maintaining a vital community of scientists and engineers, and attracting students to the field of accelerator research and development. Last but not least, the network approach could facilitate the thorny problem of site selection for new large accelerator facilities.

A shared responsibility for remote operation is technically feasible. As remote control rooms for the LHC detectors have shown, this can lead to a very effective around-the-clock operation. Clearly for accelerators much more stringent safety requirements have to be taken into account.

Operational costs would be shared by all partners. Most manpower would remain in the partner institutions, at the host site, a core team would provide the necessary on-site technical support.

A LOOK FORWARD

During the past 50 years, high-energy accelerators have not only become major research tools for nuclear and particle physics, but also influenced many other fields of science and industry by providing a powerful source of synchrotron radiation and other beams. New accelerator concepts have been the key to both an increased understanding of nature via fundamental research and the growing application of accelerators and accelerator techniques in other fields. It is therefore important to continue developing new accelerators and to maintain accelerator expertise worldwide.

However, the size and cost of future large accelerators will most likely outstrip the resources of a single region, and building them will require a new approach. The most promising is the framework of an international collaboration. A collaboration for a major accelerator facility must meet the following challenges:

- Maintain and foster the scientific culture of all participating laboratories;
- Maintain the visibility and vitality of each partner.
- All participating countries must be willing to invest and to commit themselves through long-term agreements.
- Aspects, such as national visibility, political and public identification with the project and obtaining the necessary "corporate identity" have also to be taken into account.

While much thought is given to new accelerator technologies, more needs to be done in preparing the necessary conditions for global projects. Here, ICFA and the community of accelerator builders will have to work together to generate the best ideas. Conferences like IPAC are a perfect forum for such discussions. Let me therefore wish IPAC a splendid and successful future.

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