Chapter 11

Managing the Laboratory and Large Projects

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11.1 The CERN Approach: Change and Continuity

The role and governance of CERN

The principal mission of CERN is to provide large-scale facilities for performing and analysing experiments related to high energy particle physics. This European laboratory was founded in 1954 to foster collaboration and rebuild confidence between scientists who until ten years earlier had been confronted in a devastating war. From the beginning CERN was to have the ambition to provide world-class facilities that would allow European scientists to engage in fundamental research on a par with the opportunities existing outside Europe, particularly in the USA. The scale of the accelerators and infrastructure, and the personnel and financial effort required for this kind of research had reached such a level that the nations of Europe had to pool resources to build them and thus remain internationally competitive. The CERN Convention, signed in 1953 between 12 founding member states, entered into force in September 1954. This remarkable and visionary 32-page document, sets out the rules for the governance and the purpose of the Organization [1]: "… to provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published and otherwise made generally available."

The governing body of the Organization is the CERN Council, consisting of two delegates from each member state. The Council is assisted by the Finance Committee (FC) dealing with all issues of personnel and material budgets, and the Scientific Policy Committee (SPC) advising the Organization on the research agenda. Council allocates the annual budget, with funds provided by the member states in proportion to their Net National Income (capped for any one member state, via a formula, to be less than 25% of the total budget). In order to provide a stable funding profile, to enable planning of the medium and long-term scientific programme as well as the day-to day running of the laboratory, a system of five-year rolling forecasts (“Bannier procedure”) is applied. Each year the budget for the following year is established, together with firm estimates for the following two years, and provisional estimates for the subsequent two years. While the delegates are briefed by their ministries to hold a certain line, the CERN Council has maintained the authority to negotiate and take decisions in the interest of the Organization, largely without permanent consultation with the governments.

In order to make the best use of worldwide resources, the CERN programme is harmonized with that of other laboratories. The CERN Council is kept informed by the European Committee for Future Accelerators (ECFA) and the International Committee for Future Accelerators (ICFA) concerning the scientific merit and advisability of undertaking new large projects. Along with the FC and the SPC, these entities are independent of CERN.

The astounding swiftness of the implementation of CERN and the visionary scope set out by its founders still remains, 60 years on, a remarkable achievement.

The CERN Organization

The Laboratory is organized today in four sectors and a number of units, as shown in Fig. 11.1. The Accelerators and Technology, Research and Computing, Finance and Human Resources sectors are structured into departments; the fourth sector covers International Relations. The Beams (BE), Technical (TE) and Engineering (EN) departments provide the particle beams for the experiments; they are centres of excellence that work together to design, build, operate, maintain and develop the accelerator complex, including R&D for new facilities. These departments report to the director of Accelerators and Technology; projects are coordinated via the director’s office (DO). The Theory (TH), Experimental Physics (EP) and Information Technology (IT) departments are also mutually beneficial centres of excellence in their respective fields, and through which CERN assists visiting physicists; CERN physicists also collaborate in experiments on an equal footing with the external partners. The departments that handle these activities report to the director of Research and Computing. Finance, human resources and general services are provided by departments reporting to the director of Administration, and provide the regulatory environment for all activities. Certain activities are shared: the main workshops are used by the accelerator/technical and research sector; the information and communication technologies department addresses the needs of the entire laboratory, including users. Regulations on health, safety and environment are applied by an independent unit reporting to the director-general.

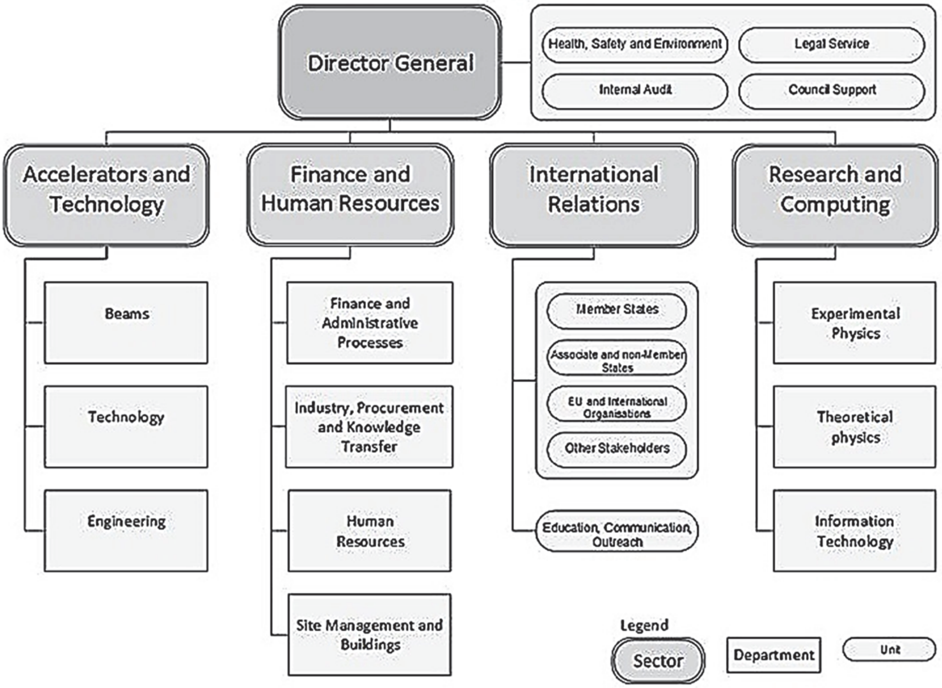

Fig. 11.1. Functional organigramme of CERN in 2016.

Directors, department heads and the director-general, who leads the laboratory, are appointed by the CERN Council. Further information regarding the organization of the laboratory can be found on the CERN web pages [2].

The overall organization of the laboratory has evolved over time; the recent addition of a sector devoted to International Relations reflects CERN's gradual evolution from a solely European entity to a broadening stature in the world. Until the 1980s all projects were administered by the departments (previously called divisions); starting with the LEP project, large accelerator and experimental facility projects are headed by project leaders responsible to the directorate. Until the early 2000s the particle beam facilities (accelerators and colliders) required for the experiments were provided by the respective divisions; subsequently it was decided to group the activities across the different accelerator divisions, to operate all the accelerators from a single control centre, and to assemble the specialists in groups in three divisions (renamed departments in 2004): Beams (BE), Accelerator Technology (TE), and Engineering (EN). Control is accomplished by a system of line management with mainly large groups (~ 100 staff) specialized in the various domains (operations, vacuum, radio-frequency, magnets, cryogenics, etc.). Most sub-projects can be handled within groups, simplifying control and avoiding the perils of matrix management, with essentially self-governing cross-group teams being formed to tackle very large projects. In the research sector the experiments are proposed, and largely staffed, by teams of researchers from external laboratories and universities. CERN groups participate in the experiment collaborations and, coupled with a few technical groups, cover particular needs and do the bulk of interfacing with the CERN infrastructure. The research sector has seen an explosion in the number of users, and the accelerator sector an increase in the complexity of the machines, obviously influencing their evolution. The technical and research sectors benefit from a collaborative administrative sector whose work has also become more complex with time.

CERN is an international organization, with staff drawn mostly far from their countries of origin. This has reinforced the international atmosphere of the laboratory and helped the users to integrate. Importantly, since the beginning, the staff has been motivated by the desire to achieve a common goal, in a constructive and non-bureaucratic collaboration between the sectors, building on their strengths and with a shared commitment to the Organization.

Style of Management

CERN has earned a reputation for developing state-of-the-art technology, the result of the collaboration of creative people in technology and research, covering a large spectrum of competence and coming with different cultural backgrounds. To "lead" and "manage" this staff requires certain talents: done properly it encourages efficiency, and includes the ability to judge when to stop "improving". Leaders and spokespersons are chosen from those who have earned the respect of colleagues, based on their scientific and personal standing or their technical achievements. In fact, in both the accelerator and research sectors the real motivation is provided by agreeing on a common goal, which can essentially always be achieved by rational discussion on scientific and technical grounds (notwithstanding shows of emotion and passion in certain circumstances!). Thus CERN's managerial decision model can be qualified as being one of "bounded rationality", a concept developed by Nobel laureate Herbert Simon [3]. Many of the ideas discussed in this book originated from scientists[a] and technicians actually doing the work, not their hierarchical leaders. Obviously, large accelerator projects and experiments must have a certain level of coordination, but for this to be efficient it must be done by staff respected for their technical competence, and their ability to recognize viable ideas when proposed. In the accelerator sector the

[a]At CERN, professional engineers and research, experimental and applied physicists, enjoy equal status and are referred to as scientific staff.

practice has been to vest group leaders with the necessary authority, and for them to hold the agreed budgets, and bear the responsibility for group activity. It has been found to be important to avoid appointing purely administrative group leaders, unable to provide respected technical leadership. The effective management structure is remarkably flat (especially in the research sector).

A further important aspect is responsible procurement of technical equipment, i.e. aimed at procuring at minimal cost to the Organization while balancing industrial returns to its Member States. How has this been done? The method has consisted of (i) performing a comprehensive cost/performance analysis of all projects, (ii) defining and applying a set of simple, fair and transparent purchasing rules, and (iii) empowering competent individuals or small teams to define goals consistent with the planning of the laboratory, and allowing them to achieve those goals with minimal bureaucracy and cost.[b]

By far the most important element in an organisation such as CERN is the quality of the staff, and this in turn depends on the ability to recruit and retain appropriate personnel, and to provide them with professional perspective. Thanks to its reputation and relatively competitive employment conditions, CERN is able to recruit and retain highly qualified staff.

Evolution of management in the accelerator sector

The management of CERN sectors has evolved over the years to take into account the continuous enlargement of the accelerator complex, and constraints on recruitment following a series of reviews of the Organization by external committees appointed by Council. Similar to other organizations, the staff complement increased rapidly in the period 1955–1970, peaking at about 3600 in 1979. Then, following the recommendations of the external committees, recruitment virtually stopped and numbers were steadily reduced, stabilising around the present complement of 2500. Almost no new staff was recruited for the LEP project, requiring a major redeployment of personnel both within the accelerator sector (closure of the ISR), and from the research sector (Experimental Facilities division) to the accelerator sector (with a consequent reduction in the service for the experiments). Towards the end of the 1980s new recruitment was authorized for about one in three of the posts liberated by an early departure scheme. This had become sorely needed with the appearance of the LHC project, but the approval of the construction of this machine was assorted with a further directive to reduce staff numbers. To face this challenge the accelerator sector

[b]In line with this approach CERN has pioneered since the 1990s the electronic issue and handling of administrative documents, aiming at a paperless administration.

underwent a major reorganisation, from being machine-centred to being activity-centred — e.g. having a single vacuum group, instead of separate vacuum groups for the PS, SPS, LEP etc. Similarly, the operation of all accelerators was grouped in a single control centre. This evolution was justified from the standpoint of classical management practice, and necessary for the groups responsible for operation and maintenance, which requires a sufficient pool of staff to provide round-the-clock service. It also purports to ensure perennial expertise within the technical groups in spite of repeated redeployment of personnel to projects. However, the LHC had started, like LEP, with an LHC division that assumed the responsibility for providing the main systems (magnets, vacuum and cryogenics), and despite being later renamed "Accelerator Technology Department" it continued to manage the work via a classical structure, with the department head taking responsibility as *de facto* the technical coordinator/team leader for major LHC work, in addition to providing the services for the other machines. In this way the pitfalls of matrix organization were avoided, and the staff working on the LHC did so as a team of groups, much as the teams on the large experiments, working towards a well-defined common goal. However, whereas for previous accelerator projects those who had participated in the construction continued to work for the machine they had built, taking an interest in its operation (an arrangement that often led to the acquisition of new competencies and the development of improved equipment), operation is now squarely in the hands of the operations team, and contact with the equipment groups is looser and more in the nature of a service. Today, the medium-size project to upgrade LHC luminosity is being handled as if it were a very large future accelerator project, with many collaborations, and in addition has adopted features of matrix-style organization. Time will tell whether this evolution is good for CERN.

Unlike large corporations, CERN is not free to hire and fire. This requires that staff remain flexible in supporting the goals of the organization and adapting to changing requirements. And change there was! The number of user scientists passed from hundreds in the 1970s to thousands in the 1990s and now stands at about 12 000. In parallel the number and complexity of the accelerators also grew: the increase in size, from the 6 m diameter synchrocyclotron to the 8.5 km diameter of LEP/LHC is impressive, but does not do justice to the true magnitude of the evolution. A corporation might have increased staff numbers, but CERN had to respond differently. It developed collaborations with outside laboratories for building accelerators, as was done (on a much larger scale) for the experiments. For the LHC, about 15% of the value of machine hardware was delivered via such collaborations (compared with about 80% in the case of the large experiments). This included the beam transfer magnets (BINP, Russia), the development and production follow-up of main ring superconducting quadrupoles (CEA, France) and cryostats (CNRS, France), the final focus quadrupoles and cryostats (Fermilab, USA, and KEK, Japan) and superconducting corrector magnets (DAE, India). CERN also benefited from the work of contingents of scientists and technicians from DAE, India (to staff the round-the-clock magnetic measurement campaign), and IFJ PAN, Kraków, Poland (to help with the installation and commissioning of the magnet protection system). CERN provided close expert oversight for such work, to ensure timely delivery of quality equipment and conformity to standards. Such arrangements rely heavily on the availability of core competence at the host laboratory and the strong motivation to achieve the goal, be it a working accelerator or working experiment.

In-kind contributions of equipment

The preferred way of acquiring equipment is via competitive tender from industry, using a detailed technical specification, if necessary based on model and prototype work done previously at CERN [Highlight 11.2]. In recent years supply via in-kind contributions from external institutes or laboratories have become more frequent, especially in the research sector, but also in the accelerator sector, as cited above. Although the in-kind supply may be free of charge to CERN it is not "free" for the project: it requires additional coordination, and reduces the degree of control CERN may deem necessary — a risk it has had to learn to take.

Additional monetary contributions from non-member states can be especially efficient, as they allow CERN to enlarge the tendering process. As an example, following Japan's special contribution to the LHC, firms there bid successfully for crucial advanced-technology equipment such as cold hydrodynamic helium compressors, high performance superconductors, and special steel.

While the LHC has so far only produced a few percent of the total number of collisions foreseen, options are starting to be discussed for a next large accelerator project. Such machines would cost much more than the LHC, and would almost certainly require truly worldwide funding. Could the model of the LHC experiments, which were funded at only 20% via the CERN budget, be adopted for financing a new accelerator?

In contrast with the experiments, a major fraction of the cost of a collider is (i) the civil engineering, and (ii) multiple units of a single sophisticated component. The quantities are such that they have to be produced in industry. This reasoning has led the proponents of the International Linear Collider (ILC) to consider in-kind contributions from designated regions that are possibly of a different design but "plug-compatible", bought from regional industry and controlled by regional "hub" laboratories. This ought to be possible, but would rely on there being a strong, competent central group, probably based at the host laboratory. It is generally understood that the civil engineering would be donated by the host region; together with the necessary oversight and central coordination, and procuring some key equipment, the minimum cost to the host region is plausibly close to 50% of the total. This is the starting assumption for discussions on how to fund the ILC; for ITER, hosted in France, the EU is contributing about 45% of the total cost, with the other six regional parties contributing about 9% each [4]. It would arguably be less risky and more economical to manage the funds for building a large new accelerator through the host laboratory, placing contracts worldwide via competitive tender, eventually featuring a degree of fair return on their expenditure. This is discussed in more detail below.

In-kind supply of qualified technical assistance

The testing, installation and quality control of equipment for a large accelerator project involves peaks of activity that call for more personnel than CERN can possibly provide. An efficient in-kind contribution is that of competent staff on secondment for a limited period during these peaks of activity — provided qualified technical supervision is available. This approach was adopted for the LHC magnet testing and the electrical circuit quality assurance referred to earlier.

Collaborations

In the accelerator sector, outside laboratories collaborate increasingly in design and prototyping work. This is clearly important when laboratories have specific expertise in domains not well covered at CERN. In this approach, (i) the collaborative sub-projects have to match the competence and infrastructure of the external laboratory; (ii) there must be effective liaison, recognizing the usual iterative design process; however, (iii) by concentrating on coordination, CERN technical staff is increasingly engaged in dispatching work to others. This has to be balanced with the need to maintain and develop core technical competence [5].

A collaborative response to requests for the transfer of know-how in core activities to external laboratories is part of the mandate of CERN. Occasional secondment of staff to work on projects elsewhere is also part of CERN's mission, and serves to enhance its visibility.

Over the last decade, CERN has become increasingly involved in the EU Framework Programmes (FP) such as CARE (Coordinated Accelerator Research in Europe) and EuCARD (European Cooperation for Accelerator Research and Development) together with a large number of laboratories. The EU FP are an excellent initiative, encouraging small teams to enter into cross-border scientific collaborations, with the possibility of attaining critical mass for specific R&D. There is also a clear sociological dimension. But with it comes a different style of control and reporting, typical of the EU programmes. CERN has shown in the past that it is capable of adapting to changing conditions: one has to be confident that it is able to absorb the additional constraints for the small fraction of activity addressed via EU-funded programmes. For most activities within the accelerator sector CERN can continue to apply the method proven successful over the years, namely to take advantage of in-house technical competence for design and model work, to purchase series equipment through contracts via normal competitive tender, and to transfer technology via close technical follow-up of manufacture.

Coordination

Coordination of large projects is obviously necessary. It is generally recognized that this is best left to those having the technical expertise and leadership ability. In the case of CERN, big projects, such as a new accelerator, are broken down into sub-projects, the leaders of which coordinate the sub-projects, resolve technical issues, and ensure respect of interfaces. Indeed, once the sub-projects have been allocated to competent and responsible technical groups, the remaining problems show up at the interfaces. It is the role of the project leader to organize structured meetings on a regular basis to track progress and manage changes at the interfaces. Between competent staff this goes smoothly with a minimum of meetings and reviews, thanks to a clear definition of the agreed goal.

In contrast with accelerator projects, the role of coordination is somewhat different for large experiments, built up from many collaborating institutes, and where decision-making is essentially via consensus. This requires clearly spelled-out management procedures, enshrined in the “Constitution of the Collaboration”. After an initial learning phase this “management by consensus” has proved its worth, witness the swiftness and quality with which the LHC experiment collaboration have produced their scientific results.

Reviews

The use of reviews to examine technical choices and monitor progress of the major accelerator projects started with LEP, i.e. when the control of such projects passed nominally from the divisions to the directorate. However, reviewing the many sub-projects of the main project has only recently been adopted in the accelerator sector. The function was previously within the purview of the machine advisory committees, which reviewed on a regular basis the whole project, including sub-projects. CERN also had to participate in the process through collaborations with US laboratories, where frequent reviews are imposed. While reviews are useful — even essential, oversight does occur. Two instances of failure to detect problems at the LHC come to mind: the cryostats for the high luminosity insertions, and the magnet interconnects. In the first case a design flaw of the support system was not detected in the reviews. It was revealed during commissioning and was corrected (with some difficulty), but did not delay the start-up of the machine. In the second case the inherent weakness of the electrical splice was not pinpointed in the design review, with the well-publicized consequence of the September 2008 incident [6]. Problems may be averted by advice from reviews, but there is a real danger that they dilute responsibility. Reviews do not replace due diligence of project leaders.

The research sector has been accustomed to reviews for several decades. For the LHC experiments, the LHC Committee (LHCC) was established. With members external to CERN and the experiments, it served the important function of monitoring and providing advice, following progress and requesting remedial action if delays were incurred. This committee shares major credit for the remarkable operation of the experiments and the quality of the research results.

Patents

Most of the ideas that were conceived and developed at CERN, some of which even led to the award of Nobel prizes, have been published to make them available as common intellectual property, and not patented. Several studies [7–9] have shown that this policy has led to significant indirect added value, beyond direct commercial interest, for companies involved in producing material for CERN, as well as for society at large. The most dramatic example was the decision of CERN to put the WWW in the public domain. However, there is increasing pressure on publicly financed laboratories to protect technology from being patented commercially, and to provide a measure of their usefulness to society at large. At CERN, while this is still mainly achieved through publication as stipulated in the Convention, the approach with regard to patents is evolving (see Chapter 10).

One should bear in mind that the concept of patenting can itself be questioned, its net utility to society not being so evident [10]. It is well known that the vast majority of ideas develop into usable technology via interaction between members of a team, and for that to happen individuals should not be tempted to keep their ideas to themselves, with the hope of eventual personal profit from a patent taken out by CERN. Added to which it is generally recognized that for institutions like CERN the effort managing a patent portfolio might be such that the cost exceeds the benefit. CERN is vigilant as to the pitfalls of patenting.

Evolution of management in the research sector

The research sector during the "learning years"

Up to about the time of the p–p̄ collider, CERN provided a large fraction of the experimental equipment. At the same time, however, many university institutes acquired the competence to develop, build and operate experimental equipment. Importantly, this helped to establish a base and visibility of particle physics in

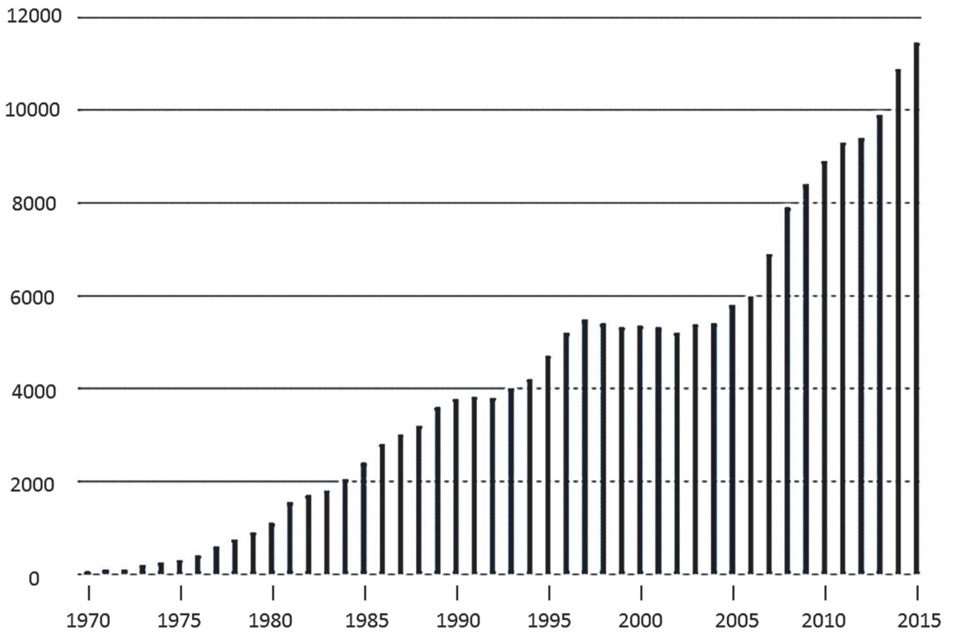

Fig 11.2. Number of CERN users vs. time.

academia. Starting with the p–p̄ collider era, experiments became large collaborative efforts with external institutions taking on a major share in providing, maintaining and operating equipment. This ever-larger involvement of the community is seen dramatically in the rising number of CERN users (Fig. 11.2).

The years to maturity

The four LEP experiments were each a collaboration of about 400 scientists, involving around 50 institutions, with CERN technical coordination and infrastructure. The evolution continued: for the LHC experiments CERN contributed only about 20% to the equipment value of the detectors, with the rest provided by the participating institutes and universities. These new conditions called for fresh ways to design, construct and operate the experiments.

CERN provided for each experiment, in addition to the infrastructure, the technical coordination, interfacing and integration, and financial control. An LHC experiment hosts up to 4000 collaborators coming from over 100 institutions. The funding of the collaborating institutions is provided by the national funding agencies in various forms and sometimes on an annual basis. It was impractical, if not impossible, to draw up legally binding contracts. Instead, the collaborations were (and are) held together via Memoranda of Understanding (MoUs). These are “best effort” agreements between stakeholders to supply selected items of equipment, cash (into a common fund) and associated personnel. Surprising as it may seem, it has worked remarkably well! The strong common interest of the stakeholders to reach the goal, and their ability to motivate and mobilize the experienced scientists, post-docs and students, were certainly important factors, but it should be stressed that the organizational framework and structure provided by CERN, the LHCC, the Resources Review Boards (RRB), and their sub-committees, have been crucial to the success of the LHC experiment projects [11].

Research at the global scale

The LHC experiments are represented by an elected spokesperson and "coordinated" (significantly the terms "managed" and "led" are avoided) by the spokesperson, aided by a technical coordinator (a recognized technical expert who takes responsibility for technical coordination and interfaces), a resource manager (who concentrates attention on funding issues), and elected scientists designated to coordinate the activities that are spread over the many collaborating institutes. The technical coordinators and resource managers are CERN staff. While it is only natural that there can be disagreements, the system is basically self-governing where governance is provided by the consensus derived from rational discussion among stakeholders, and crucially held together by the overriding desire to achieve the common goal of building a working experiment.

Apart from the experimental cavern, which is CERN-supplied infrastructure, the largest single-cost item of a detector is the experimental magnet, representing typically 30% of the value of the experiment. Up to the time of LEP these magnets had been designed and procured by CERN in much the same way as accelerator equipment. For LEP the design and fabrication of the two superconducting solenoids was outsourced (to CEA, France and to RAL, U.K.), with some CERN oversight. The normal-conducting solenoids were built at CERN. For the LHC an attempt was made to completely outsource the design and follow-up of the supply of the magnets. This turned out to be problematic for the magnets of all four major experiments, and closer control and collaboration of CERN was re-established.

In-kind contributions

The detectors of the experiments are complex but can mostly be sliced into packages of reasonable size; most of the equipment was developed and assembled in university laboratories, but sometimes it, was purchased by the institutes from industry. For the LHC, the framework for the tendering process via the common funds was provided by CERN, which often helped the collaborating institutes in this respect. Interfacing and integration was assured by the CERN group, and thanks to the effort (both technical and managerial) of the technical coordinators, the endeavour turned out to be successful. As the sources of both funding and manpower were widely dispersed, the experiments were subjected to regular scrutiny by the various committees to keep them on track with respect to technical performance, budget and schedule.

The volume of data generated by the experiments would have been impossible to handle using the computers available at the time the experiments were proposed. Decisions on data-handling equipment were therefore delayed until the last minute in order to take advantage of improving capacity (and decreasing cost), betting on the continuing validity of Moore's Law. The backbone for the data management was provided by CERN through the development of the Computing GRID, a software driven network of sharing the data and using the computing capacities of the collaborating institutes, distributed around the globe [Highlight 9.7].

Externalities

While the single-minded determination to succeed in the design, assembly and running of the very large experiments was essential, the congenial and fertile environment provided by the long-established infrastructure at CERN, its prescient Convention, the constructive support of the CERN Council and the national funding agencies, CERN's status as a leading research institution, and its location in an internationally-oriented city, have also been important factors. This should not be forgotten when trying to apply the successful formula elsewhere.

11.2 Building Large Accelerators with Industry: Lessons from the LHC

Philippe Lebrun

High energy particle accelerators are among the largest scientific instruments built by man. From their invention as table-top physics instruments a century ago — the cathode-ray tube with which J.J. Thomson discovered the electron in 1896 rested on a laboratory bench and the beam chamber of the first cyclotron built by E.O. Lawrence and S. Livingston in Berkeley in 1930 fitted in the palm of a hand — they have developed over the years in size, performance and complexity to become large technological systems, installed in multi-kilometre underground tunnels, federating the work of thousands of physicists, engineers and technicians for their construction, operation and maintenance, and relying on the series production by industry of advanced components that meet demanding specifications at market prices. Sustaining such a development over many orders