Stumbling Blocks and Milestones
The Rocky Path to the Large Hadron Collider

Hermann Schunck

To the memory of Josef Rembser, Hermann Strub and Hans Eschelbacher who served as Vice-Presidents and Presidents of CERN-Council

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1 Retired Ministerial Department Director, German delegate to the CERN Council and Vice-President from 2001 - 2004
Introduction

Figure 1: Hermann Schunck (left) with former CERN Director-General Robert Aymar at an industrial exhibition in 2005. (Photo: CERN)

The story behind the construction of the LHC, from the period prior to the decision to build it, the decision itself and then the construction phase proper, is truly fascinating and entertaining but also very instructive. The road was strewn with stumbling blocks - breakdowns, crises and even miscalculations. But in the end, it was a fabulous success story.

I would like to tell this story in the form of a personal account from my perspective as a member of the CERN Council, the highest decision-making body of the Organization. For more than 15 years, until my retirement in 2005, I regularly attended the meetings of the CERN Council and its “closed circle”, the Committee of Council, in Geneva; for a few years, I was Vice-President of the Council and at the same time chaired the Supervisory Board of DESY in Hamburg. I thus had the privilege of witnessing and occasionally helping to shape some of the developments and decisions in the field of high-energy physics.

I was not a scientist but an administrative civil servant with a scientific background. As an official in today’s Federal Ministry of Education and Research, BMBF, and in my activities for the CERN bodies, my main focus was the communication process in the institutional triangle of science, politics and administration. CERN is an ideal place for this because, in actual fact, the people sitting around the CERN Council’s large oval table are scientists, representatives of national research councils, officials from research ministries, and diplomats from more than 20 Member States.
An account based on personal experience is not a scientific record so I must offer a word of caution, right from the outset, about a risk I’m perfectly aware of: “personal account” sounds all too much as if the author wants to place himself in the limelight as the person around whom all events essentially revolved. Naturally, that would be absurd in the present case, in an international organisation with more than 20 Member States and an extraordinarily complex governance structure.

Dr Hermann Schunck, retired Ministerial Department Director, German delegate to the CERN Council and Chair of the Supervisory Board of DESY from 1999 to 2005.
Part 1: CERN and its Budget

CERN is an international organisation near Geneva on the French-Swiss border. With 3,000 employees, it operates and manages a large particle physics laboratory on the site, in particular its flagship research instrument, the Large Hadron Collider (LHC). Eleven thousand scientists from universities and research institutes around the world, who regard the Laboratory as their scientific home, use the accelerators operated by CERN. These users build and operate the large detectors of the LHC, in voluntary cooperation and using their own resources. Each detector is a major facility in its own right, technically complex and highly sophisticated. The LHC, together with its four detectors, is (virtually) unrivalled in size and technical complexity; what is more, the collaboration of several thousand scientists is an unprecedented social experiment.

Thanks to a new, innovative grid computing system (Worldwide LHC Computing Grid), yet another layer of complexity has developed around CERN. The LHC supplies vast amounts of data, which cannot be analysed immediately but, in some cases, only years later. With centres spread all over the world and the establishment of national analysis facilities - mainly in the USA, but also in Germany for example. – data analysis can be done in laboratories worldwide, with direct access to the original data.

Hence CERN and the LHC actually constitute a global network in which numerous decentralised decisions and investments have amalgamated to form a single organisation, a singular and possibly unique system. At the centre of this worldwide network sit the CERN Council and the CERN Management. The impact of their decisions and their responsibility goes well beyond the Geneva site.
More than a decade ago, the USA, Russia, Japan and Germany all still hosted particle physics laboratories operating their own accelerators. In the meantime, almost everywhere, these research facilities have been closed down or reassigned to other purposes. Naturally, many places have plans for replacement facilities, but no decisions have been taken to commence construction. CERN thus finds itself in a special position: a European laboratory with a global function. The responsibility borne by the various decision-making persons and bodies at CERN for this branch of physics is correspondingly high.

Figure 3: Four former Directors-General during the presentation of the Higgs discovery in 2012, with the incumbent Director-General Rolf Heuer in the background. (Photo: CERN)

The construction of a major facility like the Large Electron Positron (LEP) collider or the LHC always calls for the temporary creation of quasi-industrial structures in order to meet the pre-defined time frame and budget. This cannot be achieved merely at the click of a Director-General’s fingers but calls for communication, motivation, exemplarity and, finally, insight. This is why managing CERN as the Director-General is a unique challenge.

In my time at CERN, I closely followed four Directors-General, starting with Carlo Rubbia (1989-1993), then Chris Llewellyn Smith (1994-1998) and Luciano Maiani (1999-2003) and latterly Robert Aymar (2004-2008). Each is an outstanding scientist with a strong personality. I have great respect for these men; all four achieved remarkable results for CERN and although I make some critical comments about them here, with the benefit of hindsight, I do so only to draw on experience to see how major facilities like the LHC might be built in the future.

In my opinion, the succession of four Directors-General, each responsible for a chapter in the story of the planning and construction of the LHC, constituted the first serious stumbling block. Naturally, a large international organisation like CERN cannot be managed without regular rotation at its head. An extension of the term of office is a very rare occurrence; it requires “special circumstances” and constitutes a significant vote of confidence, as occurred at the time of the extension
of Herwig Schopper’s term of office at the end of the construction phase of LEP, or in the case of former Director-General, Rolf Heuer.

Having worked for around 20 years with and for major facilities in Germany and Europe, I have learned one thing: when you have a single eminent scientist who adopts such a project as his or her own, from start to finish, you have the best chance of overcoming the crises that will inevitably arise. The numerous changeovers from one Director-General to another during the planning and construction phases of the LHC represented a hurdle each time: the temperaments and management styles were too different, and the design objectives probably also shifted. Time and again, a change in the leadership of the Organization led to a break in its culture.

And yet the CERN Council was certainly wise in the choice of the Directors-General who served during the construction phase of the LHC. Before their election, Llewellyn Smith, Maiani and Aymar had each been President of the Council, Chair of the Scientific Policy Committee or Chair of an ad-hoc CERN committee, and were therefore exceptionally well acquainted with the Laboratory and the LHC project. But each changeover still constituted a stumbling block. Nevertheless, one key figure stood out, the Project Leader Lyn Evans, who was responsible for the LHC from 1994 until the start of operations. I venture to make the neither provable nor refutable assertion that, without him, the LHC would have undergone far more crises than those I will address here.

![Figure 4: Development of the CERN Budget over several decades](image-url)
The CERN Budget

Despite the undisputed importance of CERN, it is by no means self-evident that the governments and parliaments of the Member States will always be prepared to provide the necessary funds for such organisations and, in particular, for the construction and operation of increasingly large-scale research facilities. Crises have occurred time and again throughout CERN’s history, partly triggered by Member States dissatisfied with their industrial return and occasionally threatening to leave the Organization. I remember well the controversial question asked by a colleague in the German Research Ministry: “What are the disadvantages for humankind if we hear of the existence of the Higgs boson 10 years later than what the physicists dream?”

In 1990, CERN’s Budget (income) amounted to 859 million Swiss francs (MCHF); in 2000 it was 989 MCHF and in 2013 1189 MCHF (1 Swiss franc was roughly equivalent to 0.82 Euro at the end of 2012). Adjusted for inflation, the finances made available to CERN have decreased substantially over the past 20 years. This is irritating to say the least. We will now touch upon some scenarios that led to this painful development for CERN. It should be noted, however, that hardly any other scientific discipline has an organisation with this kind of budget enabling it to push back frontiers, time and again.

The largest fraction of CERN’s income stems from the contributions of the Member States; on top of these, special contributions are made sporadically by the two Host States, Switzerland and France, and finally – particularly during the construction of the LHC – substantial amounts are paid by non-Member States. The annual contribution to the CERN Budget (in 2013 about 1,200 MCHF) is not freely negotiated among the Member States but calculated according to a set formula on the basis of “net national income”. A well-established rolling, five-year financial planning mechanism gives CERN, as a rule, planning security for its long-term activities. And yet, the annual debates over finances in the CERN Council frequently produced new stumbling blocks.
In 2013, Germany’s share of the CERN Budget was a good 20% (222 MCHF or roughly 183 million Euro), followed by France (16%), the United Kingdom (15%) and Italy (12%); the lowest contributor was Bulgaria at 0.3%. Thanks to its strong economic performance compared to previous years, Germany’s share of the funding increased by around one percentage point in 2013 and might rise further in the future.

When CERN had a “normal operating structure” for the LHC in 2011, the share of the Budget given over to personnel was some 49% (approx. 612 MCHF), a reasonable proportion, as long as no (other) personnel expenses were hidden elsewhere. It is vital, particularly in times of stagnating resources, that the budget of an organisation like CERN should not be consumed by personnel expenses, and that enough leeway exists to operate the facilities and, of course, to make investments; the operating costs for the LHC alone amounted to more than 300 MCHF in both 2011 and 2012.
Part 2: The Starting Point

Figure 6: Germany’s Research Minister, Heinz Riesenhuber, visited the LEP tunnel in November 1989. (Photo: CERN)

My first halfway serious contact with the LHC project came in autumn 1989. At the Research Ministry, we were supposed to draft a speech for our Minister, Heinz Riesenhuber, to be given at the inauguration of the Large Electron Positron (LEP) collider. Carlo Rubbia, the erstwhile Director-General, stressed to us that our Minister’s speech was a unique opportunity to announce CERN’s next major project, in effect the LHC. We had to disappoint him, as we knew our Minister all too well; he liked to prepare decisions thoroughly, down to the very last detail, and without being pressed for time. Any attempt to plant such an announcement on him would not have done us, or the project, any good.

Carlo Rubbia often tried to give members of the German delegation personal tuition to bring them up to speed. He was a spirited and, for quite a while, indefatigable champion of the LHC. In his last year in office as Director-General, however, he increasingly left the tasks of science promotion and politics to his already chosen successor, Chris Llewellyn Smith.

Already during the construction of LEP, detailed studies were being carried out on a new project at CERN. Deliberations soon focused on using the tunnel built for LEP for a proton-proton collider with a collision energy of 14 tera-electronvolts (TeV). As early as 1984, various workshops were organised, which triggered the groundwork for the LHC; special attention was paid to the technical feasibility of the accelerator concept with superconducting magnets and RF cavities.

When planning the LHC, CERN was perfectly aware that it would be competing with the US project, the Superconducting Supercollider (SSC), for which
construction had started in 1991. The SSC was to be much bigger and have a correspondingly higher collision energy of 40 TeV. But Carlo Rubbia’s mantra was always “Luminosity (collision rate) beats Energy”. Competition between these two projects could easily have been a stumbling block for the smaller project, the LHC. Only when political support for the SSC foundered in 1993 did it become clear that a CERN project like the LHC would have unique discovery potential, especially to fill in the gaps of the Standard Model of particle physics (top quark and Higgs boson), but also in the search for supersymmetric particles or the quark-gluon plasma. In hindsight, especially after the spectacular discovery of the Higgs, this may almost seem too obvious for words, but I definitely recall huge investments having been made on the basis of prognoses that were really convincing at the time but eventually came to nothing. But in this case both the scientists and the Council were lucky.

Figure 7: A Session of the CERN Council in 1990. On the left, Carlo Rubbia, CERN Director-General from 1989 to 1993, and, on the right, Council President Josef Rembser of the German Ministry of Research. (Photo: CERN)

There were several milestones on the road to a final decision on the construction of the LHC, but there were stumbling blocks too. At the end of 1991, the CERN Council declared “that the LHC is the right machine for progress in the field and for the future of CERN” and the Director-General was invited to prepare the necessary documentation for a final decision within two years. A first summary technical description of the project was issued and it was hoped that physics operation could commence in 1999/2000. Director-General Rubbia proceeded on the basis of a presumed total construction cost of 2,000 MCHF (in 1991 prices), about 20% of which was supposed to be obtained through additional contributions from non-Member States.

But the final Technical Design Report, the prerequisite for a decision to build a facility like the LHC, was not approved until autumn 1995 and it wasn’t until 1998 that a complete test string, the smallest unit of components and systems from which
the accelerator would be assembled, was completed and put into operation. Carlo Rubbia had frequently given his assurance that he would ask the Council to approve the construction of the LHC only once the test string had conclusively demonstrated the feasibility of the technical concept.

In reality, the CERN Council had given the green light, in principle, for the construction of the LHC much earlier, at the end of 1994. With this decision, the LHC was incorporated into the so-called Basic Programme of the Laboratory. The attitude of the German delegation was somewhat hesitant, as Germany was primarily interested in reducing its contributions and in introducing a voting procedure that would make it difficult for it to be outvoted in the Council.

The basis for the construction decision was by no means secure and unequivocal; the Management and the Council knowingly took a high risk in “planning for success”, as it was referred to at the time. The original cost estimate in 1994 was 2,400 MCHF (in 1993 prices, not including personnel costs). In 1994, it was planned, for financial reasons, to build the LHC in two stages, the first with a collision energy of 10 TeV in 2004 (according to the “missing magnet” concept, whereby every third dipole would be missing from the ring initially), and the second, from 2008 onwards, with the design energy.

**Part 3: Reunification and the LHC**

![Image](image_url)

Figure 8: While the CERN Council was still debating the issue, prototypes had already been built by German industry. Here is a picture dated 1997.

*(Photo: CERN)*

The political environment in which this far-reaching decision for a major new facility at CERN had to be made was not particularly favourable. Certain problems, emanating mainly from Germany and the United Kingdom, cannot simply be glossed over. These problems were precipitated by the most happy event in recent German history: reunification. We should not forget that great optimism reigned in
Germany at the time. We were celebrating having seized a historic opportunity, while at the same time simply ignoring, initially at least, the costs involved in merging such disparate parts of the country.

The same thing happened with Germany’s contribution to CERN. The German delegation to the CERN Council believed, *a priori*, that the higher contribution triggered by an increased Net National Income due to reunification could be secured easily; the calculated value of Germany’s contribution had risen from 22% (1990) to practically 24% (1993) and then (from 1994) to more than 25%. It became clear, when the 1993 Federal Budget was prepared, that the heads of the Research Ministry were neither willing nor able to accept a drastically increased German contribution. Hence the only solution was to seek the Council’s understanding for Germany's special situation and to ask for the German contribution to be maintained at approximately its pre-unification level. German reunification thus became a major stumbling block.

Figure 9: Evolution of the German contribution to the CERN Budget (in % of Net National Income)

At the CERN Council meeting in December 1992, the German delegation formally requested a reduction of its contribution, in concert with the United Kingdom, which was suffering from a weakened pound at the time. The German delegation’s initial proposal was to reduce the upper limit on contributions from 25% to 20% across the board.

After lengthy discussions in the CERN governing bodies, the Budget for 1993 was reduced by 15 MCHF compared with the draft budget; furthermore, it was agreed
that the German contribution would be capped at 22.5% for the years 1994 to 1998. The German contribution in those years was thus limited to about 190 MCHF per year, which corresponded approximately to the 1990 level. German acceptance of LHC construction was coupled not only with confirmation of the contribution limit for Germany but also with a strict overall limit on contributions and substantial additional contributions by the Host States, Switzerland and France, to the tune of some 200 MCHF.

Along with some collateral technical agreements, this arrangement cost CERN about 200 MCHF compared with the previous plan. Certain other countries were also having economic and fiscal problems at the time, and the contributions of Greece, Spain and Portugal were thus reduced accordingly.

But things then went from bad to worse. In 1996, the Council decided, definitively, to build the LHC in a single phase. On this occasion, under strict instructions from the political leadership in the Federal Ministry for Research and Technology (BMFT), the German delegation demanded a further reduction in Germany’s contribution. However, the other Member States were not inclined to grant Germany more special conditions beyond the previously agreed five years. As a number of other Member States also had issues with the amount of their contributions, it was decided to make a cut across the board, by about 8% in 1997 and finally 9% from 2001 onwards. For the construction phase of the LHC, this meant a further loss of revenue for CERN of some 700 MCHF.

This stumbling block, actually more like a boulder, was ultimately overcome, inter alia by the Council’s agreeing, in 1996, to offset these cuts through recourse to loans, as interim financing for the LHC. Without this easing of the financial conditions, which definitely caused problems for a number of Member States (including Germany) due to very clear provisions in national budgetary laws, the project could easily have gone off the rails. Incidentally, the actions of the German delegation were later roundly criticised by the Federal Office of Audit.

Many crocodile tears were shed about this reduction in the CERN Budget and, according to the rhetoric of the time, Germany carried the blame. But that was not entirely fair, as all the Member States had given themselves a substantial rebate and, in so doing, many of them had cleverly hidden behind the German delegation.
Figure 10: at the Council Dinner in December 1994, following the decision of principle to approve the LHC – the German Council delegation Hermann Strub and Arno Freytag and standing behind them, Hermann Schunck and Günter Flügge. Sitting between H. Strub and A. Freytag, Helga Schmal, the DG assistant and Council secretary, with Horst Wenninger on the far left (Photo CERN)

Part 4: The project begins

Figure 11: Excavation of the upper portion of today’s ATLAS cavern. (Photo: CERN)
The numerous stumbling blocks that were strewn across CERN’s path by contemporary historical events such as German reunification and the pressure applied by various delegations to obtain reductions in their contributions or in the CERN Budget as a whole might have caused the whole project to collapse. The funding of this major new facility was seriously jeopardised, particularly as the Organization was still burdened by old debts originating from the time of the construction and subsequent upgrade of LEP.

Since the project funding showed a deficit of around 500 MCHF compared to the cost estimate of 1994, the new Director-General, Chris Llewellyn Smith, proposed that the LHC should be built in several stages and that contributions should be sought from non-Member States.

Thanks to the Director-General’s considerable diplomatic skill and the pledging of sufficient contributions by non-Member States, the Council was in a position to decide, in 1996, to build the LHC in a single stage. Start-up was now planned for 2005. The cost estimate was 2,600 MCHF. Finally there was clarity; the team was motivated and final plans could be drawn up.

The actual start of LHC construction was scheduled for 1998, once the necessary planning permission had been obtained from the French and Swiss authorities. Major civil engineering work began in 1998, and industrial production in 1999. The first in-kind payments or contributions from non-Member States arrived in 1999 from Russia and in 2000 from the USA. At the end of 2000, the project’s predecessor, LEP, was finally shut down and the tunnel was made available for the construction of the LHC. Series production of the approximately 1,300 superconducting dipole magnets began in 2001 in three European firms.

In 2001, start-up with first proton collisions was planned for 2006. The project slowly began to pick up speed. Everything seemed to be going smoothly, the concerns and wishes of the Member States had been taken into account, and the obstacles presented by contemporary events had been successfully circumnavigated.
Project in crisis

It shouldn’t actually come as any surprise that the LHC project fell into crisis before it really got started. After all, it was one of the biggest and most complex technical projects ever attempted by human ingenuity. And yet it came like a bolt from the blue when Director-General Luciano Maiani was obliged to announce, in autumn 2001, that the latest cost estimate had risen by 18%.

In spring 2001, reports of serious cost problems were already rife on the CERN grapevine. The matter was raised at the June session of the Council, but only briefly. When asked whether there were really any problems, as people were saying, Maiani replied “I don’t comment on rumours”. This was not a denial but probably just an attempt to buy time.

Then at the autumn session of the Committee of Council, Maiani reported that there were serious cost problems and announced the conclusion of a study by the Internal Audit service that the cost-to-completion had increased by 18%, from 2 593 MCHF to 3 068 MCHF, a funding shortfall of about 475 MCHF. Subsequently, more work was identified that had not yet been budgeted for, amounting to some 240 MCHF. Furthermore, a simultaneous cost review of the four LHC detectors revealed another funding gap, this time to the tune of some 360 MCHF. Even though these liabilities were not entirely or directly attributable to CERN, the overall project had accumulated total additional costs easily of the order of a whole annual budget of CERN, a huge amount.

The Director-General did not present any solution or funding proposal. It may or may not have been a coincidence that the shortfall was almost exactly equal to the reductions in Member States’ contributions in previous years. A cost overrun of
18% may seem relatively minor to us today, considering the media disaster with the railway station in Stuttgart, the airport in Berlin or even the Elbphilharmonie concert hall in Hamburg or the World Conference Center in Bonn. But for CERN, failure of the LHC project loomed large on the horizon.

I can only speculate about the motives behind the Director-General’s approach. Perhaps his dramatic announcement was engineered to get the Member States to reverse the prior reductions in the Budget and thereby relieve the cost pressures weighing on CERN. If that was so, then he had totally miscalculated. On the contrary, the Council called on the Management to submit a proposal for the completion of the LHC without additional contributions.

But Luciano Maiani himself was not entirely blameless for the funding gap that had opened up. His predecessor had left him a clear admonition, in writing, not to burden CERN with a new project; the financial situation of CERN and the LHC was simply too fraught. When Maiani took office, he decided otherwise, and proposed a new project, a neutrino beam to the Italian Gran Sasso Laboratory – really thrilling physics – which the Council was eventually unable to refuse at its December 1999 Session; perhaps some delegates might have waved it through - but with a bad conscience. The total costs, including personnel, were estimated at around 100 MCHF, half of which was borne by the Italian INFN. But beyond finances a new project always draws on scarce human and intellectual resources.

In autumn 2001, the delegations’ indignation about the financial shortfall and its magnitude was considerable, but it was more over the Director-General’s style of communication than over the cost or the funding problem itself. In their initial reactions, on the fringes of the Session, key players started asking whether the Director-General should be personally held to account. On the one hand, this seemed to me to be an entirely plausible outcome; on the other hand, a discussion along those lines in the Council would, in my view, have contributed little to solving the problem, but would instead have further exacerbated the situation. After all, the CERN Council is neither a national parliament that can install a new head of government with a vote of no-confidence, nor is it a company board of directors that can just appoint a new chief executive officer in an emergency. In an international organisation, other rules apply, which would have led to a long period of uncertainty.

At the time, I thought it would be more productive to oblige the Director-General, with his know-how and ambition, to work with all parties to find and implement a solution to the problem that had arisen. Sometime later, this is precisely what I told him: that, like others, I was quite annoyed but hoped that he would use the opportunity to get the LHC back on track for the benefit of CERN. And in this respect, Luciano Maiani did not disappoint.
Part 5: Crisis and Comeback

Figure 13: In 2003, one of the control committees at CERN, the LHC Cost Review Committee, visited the cavern which was to house the ATLAS detector. (Photo: CERN)

At its December 2001 Session, the CERN Council decided, formally on the proposal of the Director-General, to set up an External Review Committee (ERC) under the chairmanship of Frenchman Robert Aymar, an experienced research manager whom I knew well from our collaboration on the steering committee of another European research institute. Later, as a member of the Search Committee, I supported his appointment as the next Director-General of CERN. We had proposed Sigurd Lettow, then a board member of the Karlsruhe Research Centre, to serve as a German member of the ERC. Aymar later appointed him Head of Administration within his own CERN Directorate (2007).

The report of the ERC, tabled at the summer 2002 Session of the Council, was detailed and comprehensive in its diagnosis, and set out clear recommendations for action, which were then broadly implemented over the course of subsequent deliberations. CERN – both the Management and the Council – had demonstrated, by setting up the ERC and implementing its recommendations, that the Organization was capable of reacting appropriately to the crisis.

The first - and actually reassuring - observation of the ERC was that the technical basis of the project was robust and that the technical management was efficient. Of the cost overruns, only a small portion was due to the most technically sophisticated systems, namely the superconducting magnets and the cryogenics. This was above all a resounding endorsement of the LHC team and the Project Leader, Lyn Evans.
The next findings of the ERC were less gratifying, essentially implying that CERN’s organisation and resources policy had not been adequately focussed on LHC construction. The main criticism was that the LHC project had not been properly identified by the CERN Management and staff as the core mission of the Laboratory. It was stated that CERN’s organisation, based on a matrix structure, made it impossible to identify clear lines of responsibility for the individual components of the LHC. Cost control was lacking, as were risk management and appropriate financial risk prevention. Furthermore, the scheduled completion date was ambitious and entailed high risk.

The ERC submitted its own cost estimate, including project components that were still missing or booked elsewhere, particularly the internal and external personnel costs, and some contingency. The total came to a hefty 4 600 MCHF (in 2002 prices).

The ERC bemoaned the fact that the basis of earlier LHC cost estimates had been incomplete: “The cost estimate dating back to 1996 does not cover the total costs of the LHC project”. For example, a key element had been deliberately excluded in 1994, without the Council’s being informed (and without someone like me noticing), namely the extremely ambitious informatics system for the experiments’ data analysis. In fact, this was set up later (in 2001) as a separate project (Worldwide LHC Computing Grid), for which additional funding had to be found by the Member States together with the EU. The cost of the Worldwide LHC Computing Grid was estimated at 120 MCHF, but CERN actually shelled out a total of 179 MCHF.

The Aymar Committee proposed two alternative methods to reform the organisational structure of CERN, a “Board model” and a “Management model”. Robert Aymar used the so-called Board model when he took office as Director-General with just three Directors (later four). This constituted a distinct downsizing compared with his predecessor’s six-strong Directorate.

Finally, I would like to remark – in an entirely self-critical way – that the CERN Council and all its bodies such as the Finance Committee were obviously stretched to their limit in interacting with the Management and monitoring a major project like the LHC. The establishment of the Aymar Committee was like an admission of defeat, a sharp tug on the emergency brake before it was too late. But in no way do I wish to deny the Council’s ultimate responsibility for the fate of CERN and the LHC.
Relaunch

The Aymar report was the starting point for the successful relaunch of the LHC project. Director-General Luciano Maiani and the Council together broadly implemented the measures proposed by the Aymar Committee. Formal approval was given at the Council Sessions in the summer and winter of 2002. From that point onwards, responsibility for the project was clearly in the hands of the Project Leader, and not just for technical matters. A prerequisite for this was the restructuring of CERN’s organisation, with a clear focus on the LHC project, and the introduction of a monitoring system that made it possible to assess the project status at all times, be that through the resources used (earned-value management) or through an updated cost estimate (cost-to-completion). The financial situation of the Organization was eased by a loan of 300 MEUR from the European Investment Bank (EIB), an initiative taken by Director-General Luciano Maiani.

For me, one of the compelling lessons learned from the construction of the LHC was that a large and complex project with a substantial lead time absolutely requires an independent external control structure to monitor it, like the External Review Committee chaired by Robert Aymar, plus the newly instituted Cost and Schedule Review Committee, chaired by John Peoples (Fermilab). But these bodies were only set up at CERN once the project was already in progress. Finally, at the suggestion of the Aymar Committee, an Audit Committee was established, which has since coordinated the various audit activities. Thanks to the control structure now in place, the Council was once again capable of taking action.

Naturally, other unforeseeable difficulties still had to be overcome, which could easily have become real stumbling blocks, for instance problems with the many industrial suppliers. In 2002, for example, the insolvency of the parent company of the German supplier of a third of the superconducting dipoles (Babcock-Noell) was a source of concern for some time, but the order was eventually filled on schedule.

The years 2001 and 2002 were thus dedicated to overcoming the financial crisis and restructuring CERN, placing the focus on the LHC project. At the December 2002 Session of the Council, Luciano Maiani was thus able to stand up and declare “The LHC is back on track”. And in his farewell speech as Director-General one year later, he said, with good reason: “It was a good year for the LHC project”. By now, operation was scheduled to begin in 2007. The comeback was complete.
Just over a year after the Aymar Committee handed down its report, Robert Aymar was appointed Director-General of CERN, a year before the start of his term of office, as was customary, at the start of 2004. This was a logical decision in my view. Aymar was a physicist, with knowledge of the significant technological fields that were important for the LHC. But he was not a particle physicist. So there were indeed reservations among the traditional physicists of CERN. But these reservations evaporated, as I recall, when it became clear that “Aymar delivers”. His "government programme" was the Aymar report and, under his leadership, LHC construction was finally completed in 2008.

Murphy’s law strikes

It was at this point that Murphy’s Law also came into play. In September 2008, protons circulated for the first time in the LHC, but soon thereafter a major technical breakdown occurred, involving serious damage to the cooling system that ultimately called for the replacement or repair of 53 dipole magnets. This delayed the start of physics at the LHC by a whole year, which was even more annoying than the actual costs incurred, some 45 MCHF. In hindsight, it is hard to say whether the timetable for the start-up procedure was too ambitious, though it was certainly risky - or whether such an accident should have been anticipated. As a result, Robert Aymar was not able to witness the start of LHC research before leaving office. This honour fell to Rolf Heuer, who had been selected as the new Director-General in 2007. In October 2008, shortly after the accident, an official LHC inauguration ceremony was held, with the machine out of action – this was a somewhat eerie circumstance and, incidentally, my last visit to CERN to date.

It was only in November 2009 that protons began circulating in the ring once more, and first collisions were observed soon after, initially with a collision energy of 7, later to be increased to 8 TeV. From March 2010 onwards, data
was collected by the four large detectors at the LHC, 19 years after Council had requested the Director-General to draw up plans for the machine and 10 years after the shutdown of LEP! Physicists worldwide had been desperately awaiting this day; for young doctoral and postdoctoral students, in particular, delays of this magnitude, longer in total than their time until graduation, are extremely hard to stomach. I believe that for the magnitude and complexity of the accelerator and the four detectors, and the number of scientists and technicians involved up to the time of construction, a limit has been reached with the LHC that will be extremely difficult to overcome in the future.

**Part 6: The Cost of the LHC**

The CERN Management presented to the Council the full cost-to-completion of the project, according to international standards for the first time, as had been suggested by the Aymar Committee, only in the annual accounts of 2008, the year in which the LHC was commissioned. According to the figures presented, CERN had itself spent 3,685 MCHF on the accelerator, which corresponded to the so-called materials costs. Adding in personnel costs and the earlier development of the test facilities, the total came to 4,835 MCHF (in 2008 prices). It is worth recalling that the Aymar Committee had estimated the overall project cost at 4,600 MCHF in 2002 prices. So the materials costs had actually been maintained within the envelope defined, with 2% inflation and a contingency of 150 MCHF. There were no more big surprises and from that time onwards the construction of the LHC progressed in a satisfactory manner – a remarkable achievement by the LHC team and the Management, or so it appeared. As mentioned above, Murphy’s Law struck again.

To these direct costs incurred by CERN for the LHC accelerator and the experimental areas must be added the costs for the upgrade of the accelerator complex, around 153 MCHF, bringing the overall price tag for the LHC complex up to some 4,988 MCHF.

Also, the LHC could not be operated without the Worldwide LHC Computing Grid, which cost CERN an additional 179 MCHF. The bottom line was an overall cost of 5,167 MCHF.

But this does not take into account the costs of the four large (and one smaller) experiments/detectors. CERN’s direct contributions to the costs of the detectors, including materials and personnel, were reported as 1,372 MCHF in the annual accounts of 2008. That brought the total up to 6,539 MCHF. This figure can be found in the 2008 annual accounts under the heading “LHC Expenditure”; it once again clearly demonstrates that a large and complex research facility such as the LHC can only be realised through the pooling of international resources.
Table 1: Breakdown of the costs of the LHC (Source: CERN annual accounts 2008, CERN/2840).

But in another section of the 2008 annual accounts an even higher value is quoted, the LHC “net book value”, no less than 7,874 MCHF! The difference with respect to the aforementioned 6,539 MCHF derives essentially from the international contributions to the detectors (materials costs only), which were not included in the previous calculation. If you add in the unrecorded personnel costs incurred by the collaborations then the overall cost of the LHC project exceeds the staggering figure of 8 billion Swiss francs.

When the financing of the LHC was originally discussed, Carlo Rubbia had talked about securing some 500 MCHF from non-Member States. In the end, some 700 MCHF came in from international contributions – an entirely respectable achievement. The largest contribution of 290 MCHF came from the USA, followed by Russia and then Japan. However, due to differing calculation methods, e.g. for the so-called “overheads”, these contributions were only recorded in the LHC’s books as 432 MCHF, some 8% of the overall cost. The lion’s share of these contributions came in the form of in-kind deliveries of specialised components, where, ideally, the participating laboratory was a world specialist.

Figure 15: Jubilation in the control room: the LHC yields data! (Photo: CERN)
Concluding remarks

I was a part of the system for 15 years, closely involved in the decision-making process, supporting it, and even helping to shape it. Because of this, on the one hand, I feel the same jubilation that the physicists and engineers felt when the Higgs results were presented in July 2012. On the other hand, though, I still have moments of cold reflection - there were so many different stumbling blocks and high precipices that could have caused the project to fail. My abiding hope is that a few lessons will be learned from the difficult path that ultimately led to success.

It might be appropriate to ask which basic conditions have to be met for a major project like the LHC to be approved and successfully completed. The first prerequisite for a decision to proceed with construction should be that consensus exists over the scientific case for the new facility. What is its discovery potential? How many users will take part in the experiments? Can we expect any surprises, any unforeseeable new results?

In actual fact, from the outset the particle physics community had been unanimous in its view that the next major facility should be a proton-proton collider. The only doubt was whether the energies achievable at CERN due to the use of the LEP tunnel were enough to take the physics into new discovery territory or whether far greater energies would be required, like those being planned for the SSC in the United States. Today – already according to the first, completely speculative results from the LHC – we can say with some relief that the considerations of the time were basically correct.

The second prerequisite is that the technical viability of the planned facility must be investigated in as much detail as possible, demonstrated and comprehensively documented in the customary “Technical Design Report” like the one submitted for the LHC in 1995. In the case of the LHC, this also meant driving forward the development of the superconducting magnets and the RF cavities and finally building and operating a test string, which eventually happened in 1998. It seemed important to everyone who was responsible for the preparation of the LHC – in both the Management and the Council – not to jeopardise either the preparation dynamics or, ultimately, the decision-making process. The technical difficulties experienced in the magnet development and the test string were not unexpected, but they were overcome. This came at a price – due to the strategy chosen by CERN, the three firms from Germany, France and Italy who were awarded the contracts for the series production of the magnets were in a very comfortable position in the price negotiations.
The third prerequisite is a robust cost estimate. It seems obvious that a cost estimate for a complex major project should, above all, be based on a design that is as comprehensive as possible and then frozen; meeting this condition requires more discipline than has often been on display. Without clarity over the aim of the project and the completeness of the technical design, retrospective improvements and scheduling changes will always occur, with massive cost implications.

Last but not least, the fourth prerequisite that must not be forgotten is the need for a definitive financing plan, built on a realistic cost estimate that is valid for the entire duration of construction and commissioning. To avoid jeopardising this most important condition in the decision to proceed with construction of the LHC, the CERN Management resorted to playing tricks – it omitted the grid computing system and charged other parts of the project to other lines of the Budget, as was later critically noted by the External Review Committee.

In addition to these aforementioned, briefly outlined prerequisites for a decision to go ahead with a large-scale project such as the LHC, a number of other measures in the human resources and governance domains are essential for the decision to be implemented successfully and for the facility to be completed. Notable among these is the establishment of a control structure, a measure that was only partially taken for the LHC and, in fact, was only systematically introduced with the implementation of the Aymar report.

These prerequisites for the construction of a major research facility might appear trivial but they most definitely are not. I am convinced that the misery of major projects in various other fields can, for the most part, be attributed to the fact that these simple rules were flouted. To name but one notorious example from Germany, in Hamburg’s Elbphilharmonie concert hall project, design change requests were made on more than 500 work packages. The reasons for the continuing cavalier attitude towards these simple, common-sense rules may be many and varied, from political pressure to some vague hope that things will be alright in the end. Such attitudes are reprehensible in all circumstances and never go unpunished. Murphy sends his regards.