University of Amsterdam

Faculty of Science

Valedictory lecture

Golden Years - from CERN to DESY and back

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Golden Years - from CERN to DESY and back

Valedictory lecture as professor of Experimental High Energy Physics at the University of Amsterdam, 10 March 2017.

Golden Years

In this lecture I will give a very brief overview of high energy physics and its progress; I will also discuss a bit of politics and science policy and finally I will address the question: if I were to start today, would I study high energy physics again?

In 1967, now almost 50 years ago, I enrolled at the university of Nijmegen, now called Radboud University. In one of the first classes I attended, the special theory of relativity was introduced and I was fascinated. In particular the equivalence of mass and energy was intriguing. And more than that: the existence of 'elementary' particles with mysterious names like Sigma, Xi and Omega enticed the imagination. In Fig. 1 you see a page from my textbook. Some elementary particles had been discovered in cosmic rays, but many new had been produced in the laboratory, at accelerators, detected in devices

Fig. 1.
From: Beiser, Concepts of Modern Physics (Revised Edition, 1967) (McGraw-Hill Book Company).

Table 1.1

REST MASSES OF THE MOST STABLE ELEMENTARY PARTICLES

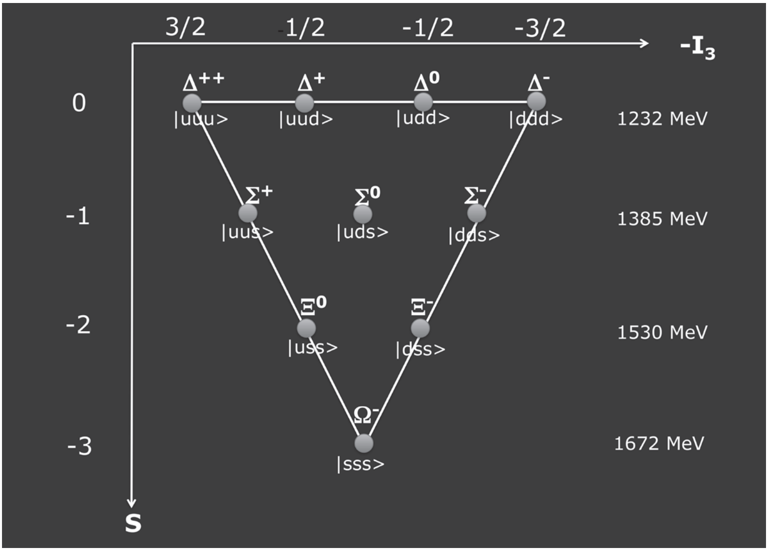
Particle	Symbol*	Rest mass, Mev
Photon	$\gamma(\overline{\gamma} \equiv \gamma)$	0
Neutrino	$\nu_e, \nu_\mu(\overline{\nu}_e, \overline{\nu}_\mu)$	0
Electron	$e(e^+)$	0.51
Mu meson	$\mu^-(\mu^+)$	106
Pi meson	$\pi^+(\pi^-)$	140
	$\pi^0(\overline{\pi^0} \equiv \pi^0)$	135
K meson	$K^+(K^-)$	494
	$K^0(\overline{K^0})$	498
Eta meson	$\eta^0(\overline{\eta^0} \equiv \eta^0)$	548
Proton	$p(\overline{p})$	938.2
Neutron	$n(\overline{n})$	939.5
Λ Hyperon	$\Lambda(\overline{\Lambda})$	1115
Σ Hyperon	$\Sigma^+(\overline{\Sigma^-})$	1192
	$\Sigma^0(\overline{\Sigma^0})$	1194
	$\Sigma^-(\overline{\Sigma^+})$	1197
Ξ Hyperon	$\Xi^0(\overline{\Xi^0})$	1310
	$\Xi^-(\overline{\Xi^+})$	1320
Ω Hyperon	$\Omega^-(\overline{\Omega^+})$	1676

* Antiparticle symbol in parenthesis.

1.10 Velocity Addition

One of the postulates of special relativity states t
free space has the same value for all observers, rega
tion. But "common sense" tells us that, if we thr
sec from a car moving at 80 ft/sec, the ball's spee
130 ft/sec, the sum of the two speeds. Hence we
light emitted in a frame of reference S' in the

Fig. 2.
The baryon decuplet. Through this classification scheme the existence of the Ω- baryon was predicted.



called bubble chambers. Bubble chambers provided spectacular, beautiful photographs of tracks of particles. Tracks emanating from an interaction of a beam particle with the bubble chamber liquid, often liquid hydrogen. Glaser, the inventor of the bubble chamber, Alvarez, who used it to discover a large number of so called resonances, and Gell-Mann who devised a scheme for classifying elementary particles, won Nobel Prizes in the sixties of last century. Gell-Mann's scheme was crowned by the discovery of the Ω^- baryon, consisting of three strange quarks. ('Quarks' were introduced in [1] by Gell-Mann and Zweig independently at practically the same time in January 1964). The scheme was based on representations of a group, SU(3).
The fundamental representation corresponded to three quarks – or three anti-quarks – 'hypothetical' particles at the time of their introduction. Higher dimensional representations corresponded to mesons and baryons. In the baryon decuplet (Fig. 2), ten-dimensional as the name says, the last entry was missing. It corresponded to three strange quarks and was discovered in Brookhaven in 1964 [2]. In Fig. 3 you see the original bubble chamber picture, beautiful, almost as beautiful as the pictures we would take with the 2m hydrogen bubble chamber of CERN! Our experiment, probably the biggest bubble chamber experiment ever, was started by Amsterdam and Nijmegen, later joined by CERN and Oxford, and took more than 3 million photographs between 1967 and 1974. One of a considerable number of resulting publications can be found in [3], the abstract is reproduced in Fig. 4.

Fig. 3.
Bubble chamber photograph showing the production and decay of the Ω- baryon. The picture shows the discovery of the Ω- using the 80' bubble chamber of Brookhaven.

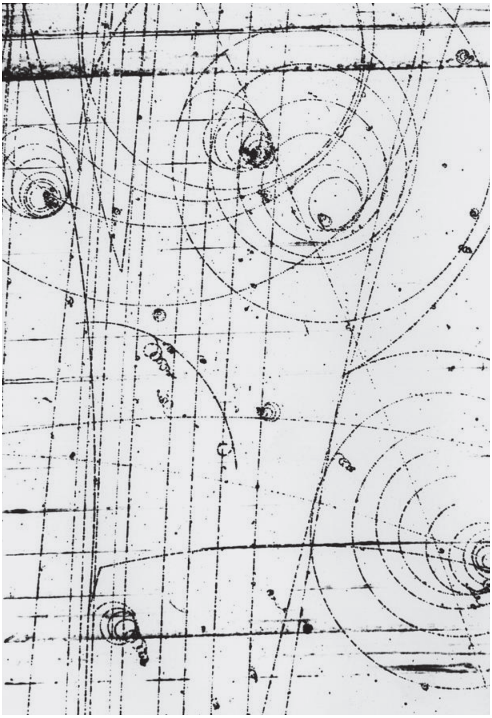


Fig. 4.
Self explained.

Nuclear Physics B

Volume 142, Issue 3, 25 September 1978, Pages 205-219

Ω^- produced in K^- p reactions at 4.2 GeV/*c*

Amsterdam-CERN-Nijmegen-Oxford Collaboration

http://dx.doi.org/10.1016/0550-3213(78)90197-9

Abstract

Forty Ω^- events have been observed in a large (133 events/μb) experiment at 4.2 GeV/*c* incident K^- momentum. Thirty nine of the events come from the three-body reaction $K^-p \rightarrow \Omega^- K^+ K^0$. The Ω^- is mainly produced in the forward hemisphere (direction of the incident K^-). The lifetime is measured to be τ = $(0.75^{+0.14}_{-0.11} \times 10^{-10})$ sec, substantially less than the Particle Data Group value of $(1.3_{-03}^{+02}) \times 10^{-10}$ sec. The mass is determined to be 1671.7± 0.6 MeV, in good agreement with other determinations. The decay asymmetry parameter α (for the decay mode $\Omega^- \rightarrow \Lambda K^-$) is found to be -0.2±0.4.

* Armin Tenner, Wes Metzger, Henk Tiecke, Jan Timmermans

I am not an author of this paper, but several of the authors are in the audience*. They must be overwhelmed by nostalgia now!

In 1971 I completed the fourth year of my curriculum and started my practical work in preparation of the doctoral exam. It was the year that Gerard 't Hooft published the article 'Renormalizable Lagrangians for Massive Yang-Mills fields' [4]. It was presented at a conference in Amsterdam by Martinus Veltman, under whose guidance 't Hooft had worked on this very tough subject. The article would change the course of high energy physics. Veltman and 't Hooft won the 1999 Nobel Prize for this breakthrough in the quantitative understanding of elementary particle interactions. Although the article would change the course of high energy physics, it did not change mine immediately... I had embarked on a study of long range, 'soft' strong interactions and it gave me great satisfaction to write my first papers and my Ph.D. thesis (supervised by Wolfram Kittel) on this subject. But the emphasis of experimental high energy physics and of my own interest would move to smaller distance scales, where the new theoretical insights gave more guidance.

In 1971 only a small number of elementary particles and fields were known (Fig.5). Most of them still hidden in the dark. Even the way in which they are organised in this cartoon (Fig. 5) was not known. (That quarks were

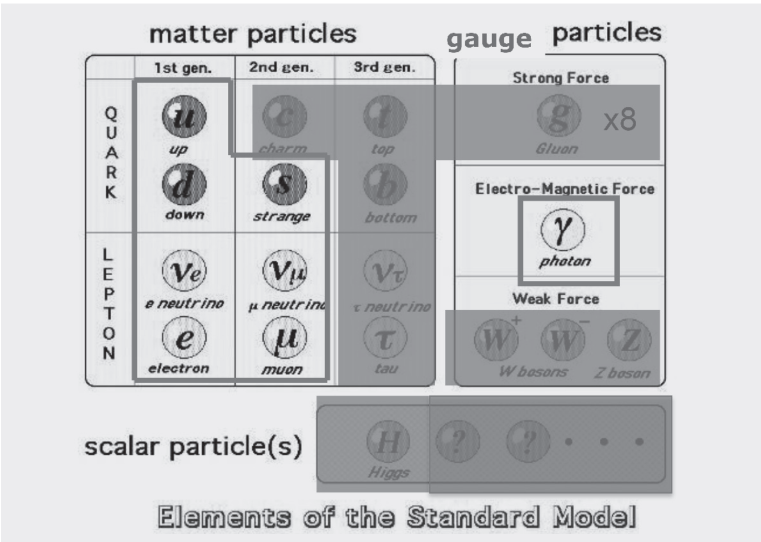


Fig. 5. Particles and fields ('gauge particles') known in 1971: three quarks ('up', 'down' and 'strange'), two charged leptons (electron and muon) and the two corresponding neutrinos. The photon was the only field quantum known at the time.

Fig. 6.
The full spectrum of particles and fields as known to date. The Higgs-boson was discovered in 2012 at the LHC (CERN), the W and Z bosons were discovered in 1983 at the SppbarS (CERN), the gluon at PETRA (DESY) in 1979; the ‘charm’-quark at Brookhaven and SLAC in 1974, the ‘bottom’-quark and the ‘top’-quark at Fermilab in 1977 and 1995 respectively; the charged tau-lepton at SLAC in 1975 and the tau-neutrino at Fermilab in 2000.

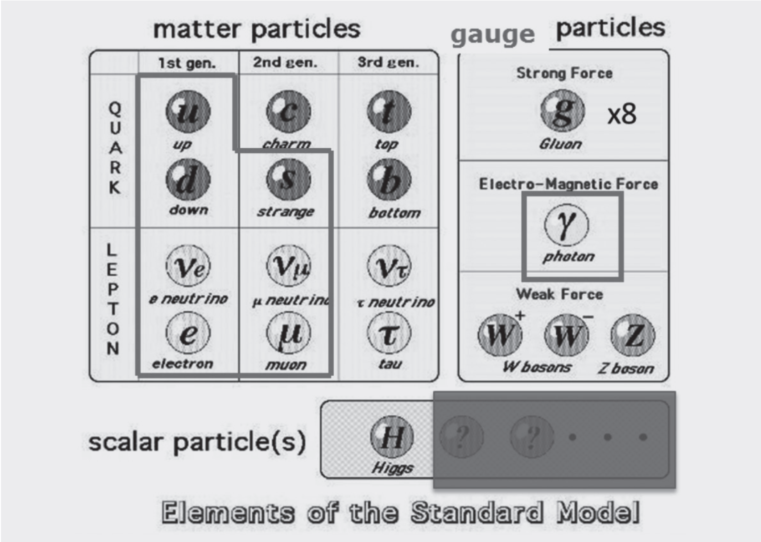


Fig. 7.
Self explained.

Physics Letters B

Volume 168, Issues 1–2, 27 February 1986, Pages 163-169

High energy photoproduction of large transverse-momentum π^0 mesons: A quantitative test of QCD

NA14 Collaboration

http://dx.doi.org/10.1016/0370-2693(86)91480-2

Abstract

The first results on inclusive photoproduction of π^0 at transverse momenta up to 4 GeV/*c*, using incident γ energies between 50 and 150 GeV are presented. A comparison is made with inclusive π^0 production obtained, in the same experiment, with incident π^-. Using the π^- data to parametrize the hadronic behaviour of the photon, significant differences are observed in quantitative agreement with QCD Compton scattering and corrections thereof.

real objects and not just mathematical constructs was discovered through the observation of deep inelastic scattering in 1969 [5, 6]). It took until 2012 to complete the picture with the discovery of the Higgs boson. Nature and nature's law lay no longer hidden in night! (Fig. 6). I should say: complete the picture of the Standard Model – we have every reason to believe that there is physics beyond the Standard Model, although for the moment it remains very well concealed from us. There is hard work ahead! A warning: there is more to elementary particles than indicated in Fig. 6: the interactions between the elementary particles and fields (see e.g. [13] for a quantitative approach).

In early 1979 I went to CERN for what I thought would be a brief period as a post-doctoral researcher. The main accelerator of CERN at that time was the Super Proton Synchrotron, the SPS, accelerating protons to 450 GeV and providing a wealth of secondary beams for the so called fixed target program. Preparations to run the SPS in colliding beam mode were already ongoing, but I found it too big a step to join those efforts. Instead I joined a group led by Daniel Treille, preparing an experiment to scatter very high energy photons, 90 GeV on average, off protons and neutrons in an isoscalar ^{6}Li target. We made pioneering tests of perturbative QCD [7] (Fig. 7), the theory of quarks and gluons, based on that same group, SU(3), this time in the role of the gauge group of colour. We also performed a direct and unique measurement of the

Fig. 8.
Self explained.

Physics Letters B

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Measurement of deep inelastic Compton scattering of high energy photons

NA14 Collaboration

http://dx.doi.org/10.1016/0370-2693(85)90521-0

Abstract

We present the first results on inclusive photo-production of prompt photons at high transverse momenta. The data were taken in an open spectrometer at CERN using a high intensity photon beam energy between 50 and 150 GeV. After subtracting the yield of photons from indirect sources, a clear excess is observed for transverse momenta above 2.5 GeVc Deep inelastic Compton scattering with appropriate QCD corrections account for this excess. The data disfavour the gauge integer charge quark models so far proposed.

quark charge (which turned out to be fractional!) [8] (Fig. 8). (This is the place to note, that looking up these 'old' references, it is remarkable that they still are behind pay walls and that there is an enormous back-log in the transition to Open Access publishing!)

The brief period at CERN lasted six years. Meanwhile the preparations for the LEP programme were in full swing - a very challenging and very innovative programme. Located in a new circular tunnel with a circumference of 27 km, this accelerator would collide electron and positron beams with energies up to 100 GeV. The primary goal was to find the Higgs boson.

But I was to join another project. At DESY, the German high energy physics laboratory in Hamburg, a unique accelerator was in preparation: HERA, an electron (or positron) – proton colliding beam facility. Walter Hoogland was at the origin and I was one of the early Nikhef members of what was going to be the ZEUS group. An exciting and very fruitful period followed. I wish everybody the wonderful colleagues and students I worked with. We explored the proton structure [9] (Fig.9) and more in new domains and set new standards, together with our competitors and colleagues of the H1 experiment. Our measurements of the quark and gluon distribution functions are now amply used in the analysis of the LHC data. This is the place to

Fig. 9.
Self explained.

Measurement of the neutral current cross section and F2 structure function for deep inelastic e+ p scattering at HERA

The European Physical Journal C - Particles and Fields

July 2001, Volume 21, Issue 3, pp 443–471

DOI (Digital Object Identifier): 10.1007/s100520100749

Abstract.
The cross section and the proton structure function F2 for neutral current deep inelastic e+ p scattering have been measured with the ZEUS detector at HERA using an integrated luminosity of 30 pb^{-1}. The data were collected in 1996 and 1997 at a centre-of-mass energy of 300 GeV. They cover the kinematic range $2.7 < Q^2 < 30000$ GeV^2 and $6 \cdot 10{-}5 < x < 0.65$. The variation of F_2 with x and Q^2 is well described by next-to-leading-order perturbative QCD as implemented in the DGLAP evolution equations.

Received: 30 May 2001 / Published online: 24 August 2001 refer to a very important analysis method, the Double Angle method, invented by Bentvelsen, understood by Kooijman and published by the three of us! [10]

Around, let us say, the year 2000, high energy physics had delivered a fairly complete picture of elementary particles and fields. Various accelerators in Japan, the USA, Germany and of course at CERN had made crucial contributions to this picture. At CERN the W and Z bosons had been found, awarded with the Nobel Prize for Rubbia and Van der Meer in 1984. CERN's flagship LEP, the large electron-positron collider was also a great contributor to laying the foundations under and consolidating the theory, the Standard Model (Fig. 10).

LEP, and all the other accelerators, had failed to deliver on one issue.

Renormalizability of the theory required a scalar particle, the Higgs boson, that had not been detected. Apparently it was too heavy and/or its production cross section too low, to be found at the Tevatron of Fermilab or at LEP at CERN. Drastic measures were required. In Europe consensus had grown for a very high energy, 14 TeV, proton-proton collider, to be installed in the 27 km long LEP tunnel. In the USA a similar, but even more ambitious project, had failed.

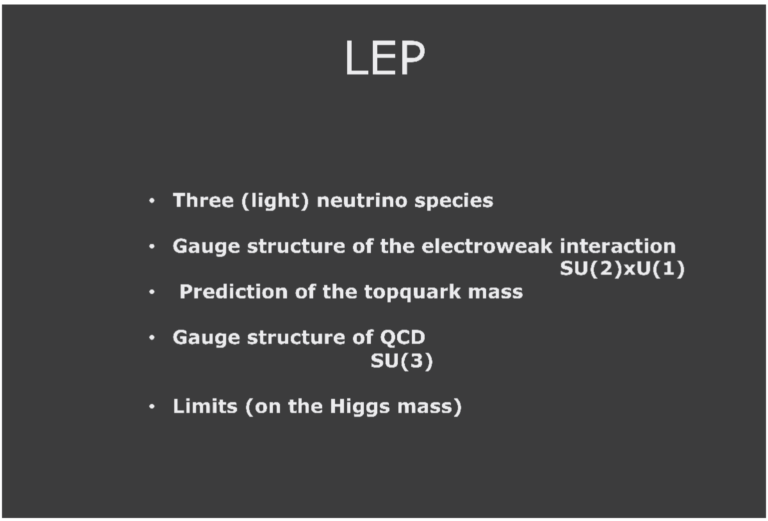


Fig. 10.
Ultra-brief summary of the achievements of the LEP programme.

Fig. 11.
Expertise in instrumentation for high energy physics.

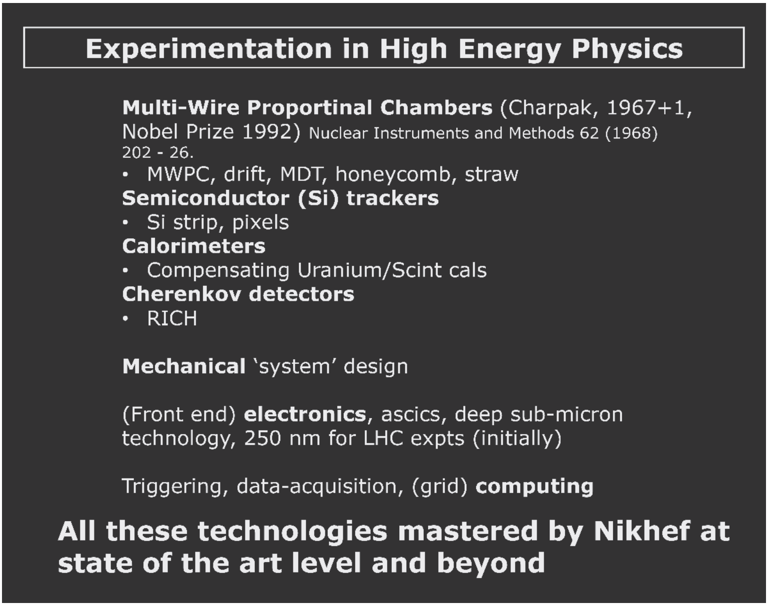
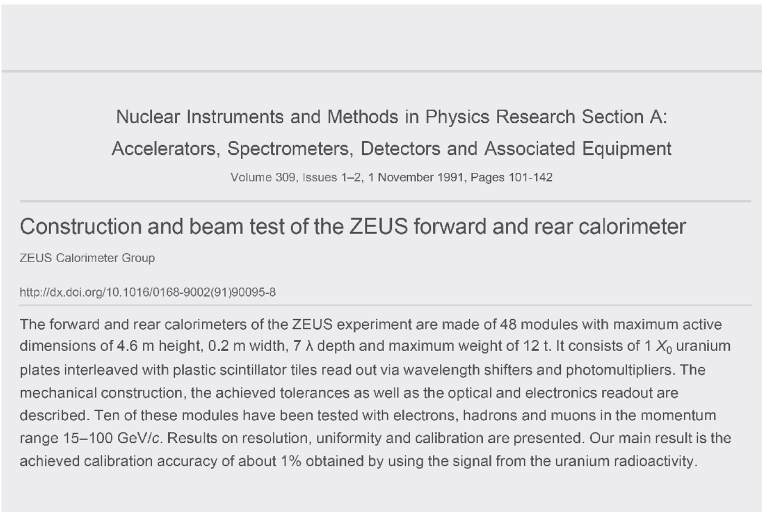


Fig. 12.
Self explained.



Nuclear Instruments and Methods in Physics Research Section A:
Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 309, Issues 1–2, 1 November 1991, Pages 101-142

Construction and beam test of the ZEUS forward and rear calorimeter

ZEUS Calorimeter Group

http://dx.doi.org/10.1016/0168-9002(91)90095-8

The forward and rear calorimeters of the ZEUS experiment are made of 48 modules with maximum active dimensions of 4.6 m height, 0.2 m width, 7 λ depth and maximum weight of 12 t. It consists of 1 X_0 uranium plates interleaved with plastic scintillator tiles read out via wavelength shifters and photomultipliers. The mechanical construction, the achieved tolerances as well as the optical and electronics readout are described. Ten of these modules have been tested with electrons, hadrons and muons in the momentum range 15–100 GeV/*c*. Results on resolution, uniformity and calibration are presented. Our main result is the achieved calibration accuracy of about 1% obtained by using the signal from the uranium radioactivity.

Over the years, CERN had secured support from non-member states such as Japan and the USA and in 2001 construction of the Large Hadron Collider could start. But that could only happen after stopping LEP and clearing the tunnel. Stopping LEP, after 10 productive years, was no easy decision. I was involved in the discussions as chair of the LHC Committee and as member of CERN's Research Board and Scientific Policy Committee. These discussions had a rational basis, of course, and for me the decision was clear: stop LEP and go ahead with the LHC as soon as possible. Even if, in the very last LEP data, hints were found for a Higgs boson with a mass close to 114 GeV, just at the kinematic limit reachable at LEP. The discussions also were emotional. Many colleagues had been intimately involved in the LEP adventure from the beginning, and then it is difficult to accept the end of an era. Insults and threats were issued using the worldwide web, invented at CERN, but not for this purpose! Other social media were not available yet!

Bert Diddens, the first director of Nikhef, section high energy physics, had created Nikhef as an institute that was capable of developing and building state of the art instrumentation. The importance of that profile for the success of the institute as an internationally leading laboratory cannot be overstated. It put the physicists of the institute, backed by a superbly competent technical staff in an excellent position to play leading roles in the LEP and HERA programs. It is impossible to do justice to all the amazing achievements in the area of particle detection in the context of this lecture. A very schematic overview is shown in Fig. 11. I do draw your attention to a crucial invention, in 1967+1, of the multi-wire proportional chamber by Charpak at CERN. Even before the Nikhef workshops were ready, the newly founded institute started mastering the art of the construction of wire-chambers in a temporary building. As Fig. 11 illustrates, the full spectrum of techniques relevant for high energy physics has been (and continually is being) developed by the technical departments of the institute. This includes techniques (the list in the figure is not exhaustive) for astro-particle physics, dark matter and gravitational wave research. In the framework of this lecture I would like to highlight the construction of a 'compensating' uranium-scintillator calorimeter for the ZEUS experiment, led by Henk Tiecke [11], see Fig. 12.

Through this profile, obviously Nikhef also was in an excellent position to embark on the LHC program, where the conditions for particle detection would be unprecedentedly harsh: pp collisions at 14 TeV producing 10^9 high energy particles per second. This put strong requirements on speed and radiation hardness of sensors and electronics. Moreover the experiments would record several 100 MB of data per second, requiring a new approach to data storage and (distributed) computing (the worldwide LHC computing grid). Successive Nikhef directors saw to it that the participation in the LHC programme became a great success, notably during the recent tenure of Frank Linde, the longest serving Nikhef director ever, so far!

In 2001 I was nominated Nikhef-director. I would become the shortest serving Nikhef director ever, so far!

My nomination was a close call. As a sympathizer, a follower if you want, of predecessors like Hoogland and Gaemers the then director of FOM was not looking forward to another Nikhef-director who, how shall I put it, acted rather independently. My immediate predecessor Ger van Middelkoop definitely assumed an independent position as well, but probably had enough charm in addition to be tolerated. If I had to start my career again, I would definitely try to be more charming!

Nikhef's LHC programme was already well underway in 2001, with significant participation in the 'general purpose' ATLAS detector and the specialized LHCb and ALICE detectors. In addition a modest but significant activity in astroparticle physics, Antares, was being developed. Meanwhile astroparticle physics, including dark matter searches and gravitational waves are an important part of the Nikhef programme.

ATLAS, together with the CMS experiment, with Jim Virdee as one of the leading figures, delivered the Higgs-boson. I remember receiving a phone-call late at night from Jim, probably in May or June 2012. 'I think we have got the object', he said. Remarkably, the first evidence came from the decay of the Higgs-boson in two photons. Jim had, from the very beginning, insisted on the importance of this channel. The expected branching ratio was only one in a thousand or even less, depending on the mass. Very high resolution electromagnetic calorimetry would, however, make this channel accessible. Notably for relatively low Higgs masses where the QCD background for channels like Higgs to b bbar would be enormous. A novel calorimetric technique based on lead-tungstenate crystals was successfully developed for CMS.

In the summer of 2003, I was two years into my mandate at Nikhef, Robert Aymar, Director General elect, invited me to become CERN's scientific director and his deputy, to start in January 2004. The five following years were incredible in many respects. Working with Aymar was an experience. I have never met anyone working harder, from early morning till late night. There was a lot to do. Working very closely with Lyn Evans, the LHC project leader and with the spokespersons of the experiments we saw the completion of the hardware and its installation making steady progress. From an empty 27 km long tunnel, with huge, equally empty experimental caverns to 'first beams' and detectors ready to receive them in September 2008. And with a worldwide LHC Computing Grid in place, including a very prominent Tier-1 centre here in Amsterdam.

Although the LEP tunnel was available, a lot of civil engineering was still required to prepare for the LHC. In particular the experimental caverns for the ATLAS and CMS experiments still had to be excavated.

I will not attempt here to explain all the technical and logistic challenges that had to be overcome in order to be ready for first beam.

One very important initial challenge was: the cryogenic distribution line (QRL), not delivered up to standards by the 'lowest bidder' who had won the contract; as a consequence of the delay the LHC dipole magnets (superconducting '2 in 1' very novel magnets) had to be stored outside (unforeseen). But this problem and many other problems were solved as they arose, both by the LHC crew and the experimental collaborations. For some organisational matters concerning the latter, see [12].

The installation of the experiments steadily passed one milestone after the other, some of the installation events were very spectacular, such as the installation of the ATLAS toroidal magnets and the lowering of the CMS central barrel, including the superconducting solenoidal spectrometer magnet.

All activities, both on the accelerator side and on the experiments side converged to readiness for 'first beam' on September 10, 2008. 'First beam' just meant: circulating beams at injection energy (450 GeV), one beam at a time, no collisions and not at full energy. There was a very large interest of the press during the start-up. Due to an amazing 'hype' there was great excitement about the imminent disappearance of us all into a black hole. Concerns that it might be dangerous to switch on the LHC in a completely new energy domain, we took very seriously, as illustrated in Fig. 13, referring to the LHC Safety Assessment Group and the Scientific Policy Committee. A thorough scientific analysis was published by Giddings and Mangano, as also indicated in the figure. But we did not manage to avoid the hype...

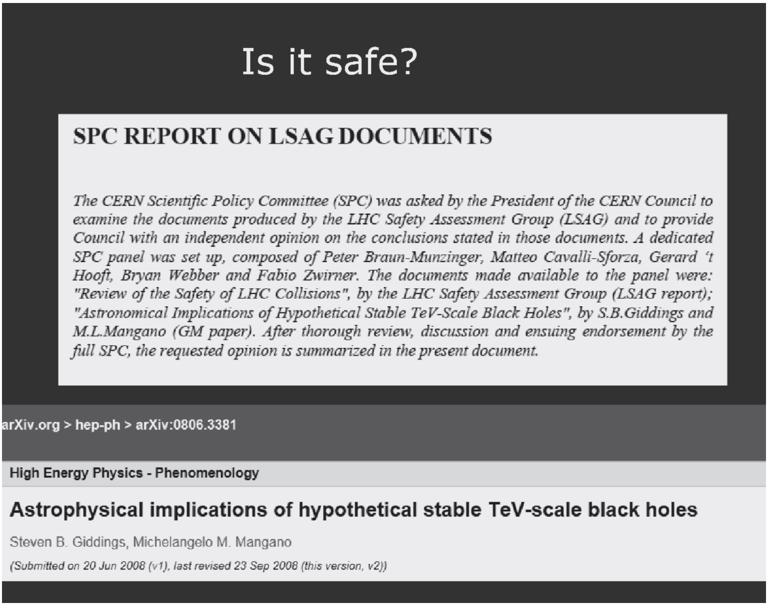


Fig. 13.
Switching on an accelerator for the first time in a new energy domain: concerns about safety.

Fig. 14.
The mission of CERN as presented to a visiting politician.

The LHC magnets are operated at a temperature of 1.9K, 1.9 degrees above absolute zero, colder than outer space. One of the thousands of welds in the superconducting cable connects had a resistance of one tenth of one millionth of an Ohm, instead of one thousandth of one millionth of an Ohm. It lead to a serious explosion on September 19, 2008. The repair took a bit longer than a year and in December 2009 the accelerator was ready to be commissioned for its first physics run.

The physics programme is exceptionally successful and productive. The discovery of the Higgs boson at a mass of 125 GeV, a spectacular success. The robustness of the Standard Model a remarkable and non-trivial result. Where are we going from here? I'll come back to it at the end.

Before drawing this lecture to a close, there is one more subject I need to discuss: politics and policy. Many politicians visited CERN, both from non-member states and from member states. In Fig. 14 a slide from the presentation at the occasion of the visit of minister Plasterk is shown. Why did they visit? To learn about CERN's mission – summarized in the figure. CERN has become a European Organization with high prestige in which, moreover, cooperation within Europe and beyond, comes naturally. I think that the common ground for cooperation, summarized in the mission, was inspiring for the politicians who visited. They never called the membership of their country into question whilst or after visiting.

At the end of 2008 I had completed my tenure at CERN. Time to go back home! After some hesitation I accepted the invitation to join the board of the Netherlands Organisation for Scientific Research as its chairman. Interesting years followed.

It has always been my point of view that an open relationship between the scientific and the political world should be the basis for modern science policy, and that it should be made clear that science is beneficial to the whole of society.

The economic top area policy was launched by the cabinet Rutte One (that started in October 2010). The national science vision was launched by Rutte Two (that started in November 2012) and lead to the national science agenda, presented to the government in November 2015. Both these cabinets had to face the international financial and economic crisis and we all know about the austerity measures leading to cuts in the national budget amounting to several

10s of billions. It was no easy task for the national knowledge organisations, in particular VSNU, NWO and KNAW to protect the science budget from significant cuts. Along with the introduction of the top area policy the 'fonds voor economische structuurversterking' (FES) had been discontinued. That was an inconsistency in government policy we had to deal with. I think we managed fairly well and there was even a small budget increase in some areas, such as for research infrastructure. But a significant increase is needed and this is the time to ask for it! Let us use the science agenda to argue for this increase, both to finance research into the questions raised in the agenda itself and for further developing our knowledge base, through talent programs like VENI, VIDI, VICI for example, and through state of the art research infrastructure: one billion Euros in addition per year. The 'knowledge coalition' supports this claim. Represented are, in addition to KNAW, VSNU, NWO: TNO, the university medical centers, the Vereniging Hogescholen, the 'topsectoren' and the private sector. The next cabinet has no choice: plus one billion!

In Fig. 15 you see me arguing with Minister Bussemaker. What I have tried to indicate is the split a scientist who defends the research budget faces. He should say the right things, but never forget what it is really about! Furthermore the scientists who, sometimes with hindsight, tell you what you should have said, are never far! (Please note that my glass is empty, whilst the minister's glass is half full!) By the way, discussing with this minister always was a pleasure. Open and interactive. She supported a broad and diverse national science agenda as opposed to a narrow one with rather artificial 'a priori' choices.

Ladies and gentlemen, let me conclude, but not before having a very brief look at the future.

Would you study high energy physics again, if you were to start today? This question a colleague asked me a little while ago. My answer was: of course! The field is as alive as ever and its challenges are as attractive as ever. Fig. 6 may give the impression that we know everything, what more is there to be discovered? What are the question marks? Are there question marks at all? Nobody knows. We still have a long way to go before all the parameters of the Standard Model are measured with sufficient precision to conclude on its completeness and consistency for example. Moreover, neutrino masses and the (Dirac versus Majorana) nature of neutrinos still need to be sorted out. Also for a measurement of the Higgs potential, the Higgs self-couplings, we still have much work to do.

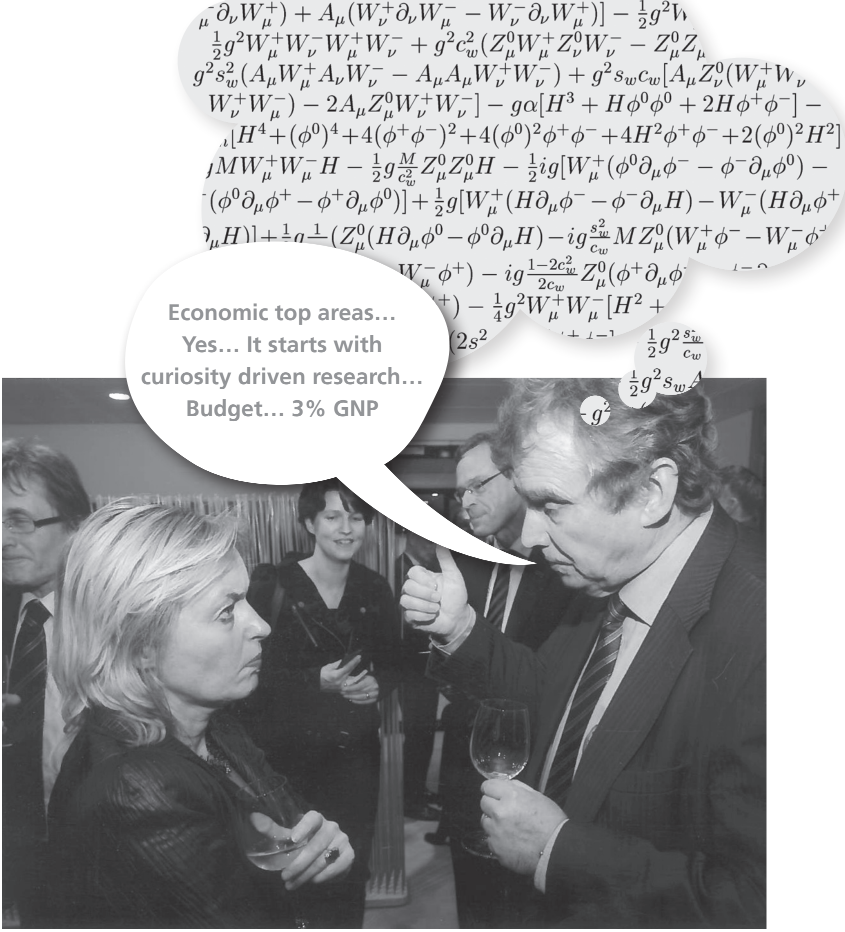


Fig. 15. Discussing science policy and reminiscing about science.

New energy thresholds, beyond the Higgs, have not been found at the LHC so far. It does not mean they don't exist. These might be the question marks. (Supersymmetry?) More statistics and much more sophisticated analyses are required. The LHC experiments and their upgrade programmes offer a perspective of 10 years.

So: more than enough work to do, but is that enough to make the field attractive for a young student? Not quite. I think we should be able to offer a really long term perspective as well. And an R&D program belonging to such a perspective. A linear e^+e^- collider of a few hundred GeV is not ambitious enough. A multi-TeV linear collider, CLIC technology or a next generation LHC, called FCC, are much more attractive. In order for CERN to have a future beyond the LHC an accelerator project catching the imagination is required. I know that many colleagues find this too simplistic a summary of the situation and I know that much more is going on. But I believe that addressing the physics beyond the Standard Model, we 'know' it has to be there, requires finding the new energy thresholds and requires going to really high energy. Nikhef director Stan Bentvelsen has energetically started discussions with the Nikhef staff and I look forward to the outcome!

Now let me finish. Let me finish by thanking those who have been important for me as teachers, as my Ph.D. students, co-workers, colleagues and friends: some of you had an explicit part in this lecture, all of you an implicit one.

Working and teaching, the latter not covered in this lecture, at this university was great. The University of Amsterdam has been a wonderful employer and I am proud to be one of its emeriti now.

Finally and most importantly: my life has been filled with joy and happiness thanks to Marlein and our children, their partners and the most lovely and inspiring grandchildren one could ever dream of: Philip, Max and Isabel.
This lecture was for you!

I have spoken!

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