Golden Years

[slide]

Ladies and gentlemen,

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 [slide], 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 [slide]. Here 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 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 [click], consisting of three strange quarks. His scheme was based on representations of a group, SU(3). The fundamental representation corresponded to three quarks – or three anti-quarks – and higher dimensional representations to mesons and baryons. In the baryon decuplet [slide], ten-dimensional as the name says, the last entry was missing. It corresponded to three strange quarks [click] and was discovered in Brookhaven in 1964 [slide]. Here you see the original bubble chamber picture, beautiful, although not nearly 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. [slide, the omega paper]. This is one of a considerable number of resulting publications. I am not an author of this paper, by the way, but several of the authors are in the audience. They must be overwhelmed by nostalgia now! [click]

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’. 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 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 [slide]. Most of them still hidden in the dark. Even the way in which they are organised in this cartoon was not known. That quarks were real objects and not just mathematical constructs was also discovered in 1971 through the discovery of deep inelastic scattering. It took until 2012 to complete the picture with the discovery of the Higgs boson [click]. Nature and nature’s law lay no longer hidden in night! 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 here, as we will see.

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 [slide], 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 quark charge (which turned out to be fractional!) [slide]. By the way as you can see on this slide Open Access comes at the expense of $39.90 according to the publisher.

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 [slide] 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. On the slide I refer to a very important analysis method, the Double Angle method, invented by Bentvelsen, understood by Kooijman and published by the three of us!

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 [slide].

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.

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 to114 GeV, just at the kinematic limit. 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 this [slide] that I will not explain here but that will be included in the printed version of the lecture. I do draw your attention to a crucial discovery, in 1967+1, of the multi-wire proportional chamber by Charpak at CERN.

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, illustrated in this primitive animation [slide, clicks]. 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, ladies and gentlemen, 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 phyics, Antares, was being developed. Meanwhile astroparticle physics, including dark matter searches and gravitational waves are 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.

In the beginning there was darkness [slide]. Although the LEP tunnel was available, a lot of civil engineering was still required to prepare for the LHC. On the slide you see the excavation of the ATLAS cavern at the bottom of a 100 m high access shaft, you see the light at the end of the shaft. You also see nine workers taking a break, and here [slide] you see those same nine workers, I presume, in suits for the inauguration. Note the LHC tunnel, up here. And here [slide] you see that same cavern again, with the first ATLAS equipment being installed. For the scale, refer to the person here. I am one of the few who know who he is.

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. Here [slide] are LHC dipole magnets waiting to be installed. It does not show that these are the result of more than ten years of R&D, with lots of high tech inside. Each of them worth a Rolls Royce car. The slide also illustrates the ingenuity of the CERN engineers. The magnets were never meant to be stored outside and the delicate ends had to be protected. They were covered by flower-pots, purchased at a local garden-center, who had their business of the year. There are 1232 magnets, with two end-caps each! Outside storage of the magnets was necessary because they could not be lowered into the tunnel [slide] as they were completed, because of a delay. The cryogenic distribution line in the tunnel had not been delivered up to standards by the ‘lowest bidder’. The problem was serious enough to be brought to the attention of the President-Director-General of the firm and even to that of the president of the republic!

I give you a brief impression of other activities [slide] prior to ‘first beam’ on September 10, 2008. The lowering of the first ATLAS toroid coil. Tilted. It illustrates that long term planning was required. Making the shaft big enough to be able to lower the coils horizontally would have been very expensive. But the ability of the coil to resist the forces as a result of the tilt had to be ‘designed in’. [slide] Here is a picture taken in the tunnel, and here another one [slide]. [slide] As you can see there was a lot of 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 on this [slide]. But we did not manage to avoid the hype.

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 [slide] 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.

Ladies and gentlemen, before drawing this lecture to a close, there is one more subject I need to discuss. Politics and policy [slide]. Many politicians visited CERN, both from non-member states [slide], this is a former president of Pakistan making a pledge, and from member states. [slide, welkom Plasterk]. Why did they visit? To learn about CERN's mission – summarized on the slide. 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. Look at these cheerful politicians [slide Ronald, slide Maria].

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 [slide] 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' 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, seen here [slide] together with two ministers and a state-secretary 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! The knowledge coalition is very motivated to defend this point of view! [click].

Here you see me arguing with Minister Bussemaker [slide]. 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. Here you see half of Ben Feringa. And then, ladies and gentlemen, 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.

[slide] 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. This picture [slide] may give the impression that we know everything, what more is there to be discovered? What are the question marks? Nobody knows. Are there question marks at all? First of all: the interactions between the fundamental particles and fields might be more involved than represented on this coffee cup. This [slide], indeed, is a more complete picture. Note the possible sign error in the formula! 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 are not taken into account in this formula, so it is incomplete. For a measurement of the Higgs potential, the Higgs self-couplings, we still have much work to do.

New energy thresholds, beyond the Higgs, have not been found at the LHC so far. These might be the question marks. It does not mean they don't exist. 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 muli-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 of you 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 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 Marc, Roel and Benne, Joo Yeon and Danique and the most lovely and inspiring grandchildren one could ever dream of: Philip, Max and Isabel. This lecture was for you!

Ik heb gezegd!