The theory works! What now?

Professor Veltman has made decisive contributions to high energy physics. Let me first very briefly sketch the context.

Fascinating experiments carried out around 1910 led Rutherford to a revolutionary new look at the structure of matter. α particles from a naturally radioactive source - the particle accelerator of those days - experienced hard collisions with apparently small objects in a thin gold foil: the atomic nucleus was discovered. The electron was known already and thus Rutherford and Bohr could formulate the atomic model: negative, light electrons circle round at a large distance from a heavy, positive nucleus. As far as we know electrons are infinitely small, 'pointlike' as we say. It was also found that nuclei consist of tightly bound objects: protons and neutrons. Since 1970 we know that these in turn consist of 'pointlike' quarks and that is it: we know the structure of matter down to the most fundamental, pointlike, level! Well, as it turns out there is more, much more...

Yet, now, in the year 2001, we have a well-organized and clear picture of the structure of matter.

Well-organized, because the number of elementary - 'pointlike' - particles in nature is small. In addition they can be neatly arranged in families. Clear because we know the interactions that these particles exert and experience. This means that we can calculate properties like their lifetime, their magnetic moment, their probability to collide with another particle. Calculate means predict - or 'postdict'. A quantitatively correct calculation, verified by experiment, is as close as we can get to understanding nature.

However, our picture is also deceptively simple because in all its simplicity it raises questions that we have not even begun to answer. For example the question what the well-organized arrangement of particles in three families is trying to tell us.

Professor Veltman has made decisive contributions to the proof of the renormalizability of gauge theories. Gauge theories are characterized by the fact that the fields that mediate the forces between particles can be chosen in infinitely many ways but according to a precise prescription. All these choices then lead to the same interaction energy. With the proof of renormalizability the way was opened to quantitative, experimentally verifiable calculations of interactions and properties of elementary particles. For this work Martinus Veltman was awarded the 1999 Nobel Prize in Physics, which he shared with his former student and later colleague Gerard 't Hooft. Their work has drastically changed theoretical physics: many books were suddenly obsolete and it became clear that gauge invariance is a property as fundamental as for example Lorentz-invariance (underlying Einstein's theory of relativity) or the uncertainty relations (underlying quantum mechanics).

Thanks to the work on renormalizability and thanks to ideas of Glashow, Weinberg, Salam and others and of course also thanks to a large number of experimental discoveries we now know the model that is realized in nature.

Let me briefly sketch what we knew in the early seventies when the proof of the renormalizability of gauge theories was completed. We knew three quarks. Initially a small number of new so-called elementary particles had been discovered in cosmic rays. From the late fifties, successive generations of particle accelerators became available and one new particle after the other was discovered! It was a first great triumph of modern particle physics that these tens of new particles could all be 'understood' in terms of only three different constituents: quarks. Originally many thought that quarks were no more than a mathematical trick and that they did not really exist. In 1970 it became clear, however, that electrons if brought into collision with protons at sufficiently high energy, penetrated deeply and hit hard kernels: quarks. So they are real, including their rather bizarre properties such as an electric charge that is a fraction exactly 1/3 or 2/3 of the electron charge. And in spite of the fact that apparently quarks cannot exist as free particles.

Furthermore we knew the electron, the muon - a heavier version of the electron - and the corresponding neutrinos. And we knew the photon, the quantum of light and that was it!

New experimental opportunities, such as offered by the development of multi-wire proportional and drift chambers, semi-conductor detectors, hermetic calorimeters, the fantastic progress in the field of fast micro-electronics etc., have allowed creative experimentalists - at least those enjoying good infra-structural support - to make a wealth of discoveries during the past 30 years. Driven by the right intuition and sometimes guided rather precisely by the theory that was developing they discovered: three new quarks (charm, bottom and top); a new kind of electron (tau) and the corresponding neutrino; the gluon, a kind of photon that binds quarks together; the charged W bosons and the neutral Z boson - field particles that explain radioactivity and the burning of the sun.

Although a theoretical physicist 'pur sang' professor Veltman has always taken a very keen interest in experimental results and in the quantitative verification of theoretical ideas. Therefore the promotion of experimental high energy physics has always had his attention. He was one of the initiators and an influential advocate of the realization of the Dutch National Institute for Nuclear Physics and High Energy Physics, a collaboration of the University of Amsterdam, the Free University, the Universities of Nijmegen and Utrecht and of the foundation FOM. At NIKHEF professor Veltman has always been a welcome guest. Not a guest, by the way, whose presence remains barely noticed, on the contrary, as also neighboring institutes regularly notice.

Experimental results sometimes have the first but certainly have the last word. Many of the experimental findings that now fit so beautifully in the Standard Model of the elementary particles and their interactions were a complete surprise, such as the discovery of the charm quark at Stanford and Brookhaven in 1974. Other discoveries were 'announced' discoveries but required an experimental tour de force such as the discoveries of the W and Z bosons at CERN in 1983. The six quarks, the six leptons and the field particles - foton, gluon, W and Z boson - everything fell into place wonderfully. The developments that led to the present picture form an exciting story as told in a brief and brilliant sketch recently written by professor Veltman entitled 'Elementary Particle Physics' aimed at interested laymen and pupils.

The sketch 'Elementary Particle Physics' ends with reference to 'relatively small uncertainties related to yet another particle, the Higgs particle'. But we also read that 'there the problems are somewhat deeper'. It appears that the Standard Model, THE renormalizable relativistic quantum field theory, can exactly accommodate all known elementary particles and fields but is not renormalizable without at least one additional particle. This we call the Higgs particle. Where to look for it, in particular which mass it has: that the theory does not tell us! So: the experimentalists are on the ball.

In the Large Electron Positron collider (LEP) at CERN, the European Center for Particle Physics of which the Netherlands are one of the founders, electrons and positrons (the anti-particles of electrons) are brought into collision. Last year an energy of 208 billion electronvolts, thought impossible not so long ago, was reached. That is an energy that we cannot simply obtain from the plug-socket, that is why we need accelerator centers like CERN. The formidable success of LEP has allowed quantitative verifications of professor Veltman's theoretical work and has yielded wonderful results. It is also correct to say, that, vice versa, LEP owes its success to the theoretical work. I mention two of many highlights. It was shown that there are three and not more than three particle families. So we do not have an 'unbounded' periodic system of fundamental particles. The mass of the top-quark - $E = Mc^2$ forbids its production at LEP - was predicted quite accurately, i.e. measured indirectly through subtle quantum-mechanical effects called radiative corrections. The calculation of such corrections is only possible in the framework of a renormalizable theory. This measurement, closely interwoven with the theoretical context for me belongs to the absolute top scientific achievements ever. It was proven correct when the top quark was produced at Fermilab in the United States.

We have learned a lot, but we have not found the indispensable Higgs particle! Even in radiative corrections it manages to hide very well. Other than for example the top quark it turns out to have only small measurable effects as shown by professor Veltman and named in his 'screening theorem'. In 1980 he published a calculation that was far ahead of its time, showing that LEP, for which the plans were still in a very early stage, should be operated at an energy of at least 250 billion electronvolts. Then there would be a chance to draw the Higgs particle out. His arguments put forward in discussions in CERN's Scientific Policy Committee did not have the desired effect. Now, more than 20 years later, we know that he had the right idea, but at that time the step was way too big, technologically and psychologically. Given the limited length of the circular LEP-tunnel of 27 km and given the electricity bill 208 billion electronvolts really was the ultimate limit.

It is widely believed, not necessarily by professor Veltman, that the Higgs particle is the result of a mechanism called spontaneous symmetry breaking. Spontaneous symmetry breaking tells us that the energy of the vacuum, empty space, has its minimal value at a non-zero value of the Higgs field. The vacuum is not really empty in that case. Empty space does not exist! Linde and Veltman were the first to, independently, realize that this should have cosmological consequences. The fact that space is practically flat seems to contradict the presence of a Higgs field. Cosmologists, of course, cheerfully find one or two or three ways out of this, but may be someone still has to get a really good idea. Let us not wait for that and prepare the next, experimental step.

We are going to use the LEP-tunnel for housing a completely new accelerator: the Large Hadron Collider LHC. It will accelerate protons. On a given circle these can be brought to much higher energies than the lighter electrons of LEP: 7000 billion electronvolts in stead of 104 billion. This is the way in which we are going to explore the Higgs sector. It is not the most elegant way, because protons are composite and strongly interacting particles, both of which electrons are not. This will lead to unprecedented particle rates and densities that require the development of new experimental techniques. The experimentalists have decided to take up this challenge, because it is the only way of having soon, six years from now, the beginning of an answer to the question: is there a Higgs sector? If yes: how does it look? If no: what is the way out Nature has found? I may have created the impression that finding the Higgs particle will be the answer to everything. That, of course, is not the case. Finding the Higgs particle is a very concrete challenge. Meeting this challenge will open up new worlds, possibly new worlds 'beyond the Standard Model'. All the other questions we have, in particular about the intriguing simplicity and order, but also about the 'arbitrary' masses of the elementary constituents, all these questions may find an answer in the process but cannot, at the moment, be approached by a very specific experimental programme. So: let us take the next step, enter the Higgs sector and find out what happens. We will certainly acquire new knowledge and new understanding will arise from this.

The developments in particle physics continue to be very exciting. For us it is a pleasure to offer professor Veltman the opportunity to follow the developments from the front row, to make his comments and, if he so wishes, to enter the arena as an honorary professor of the University of Amsterdam.

I would now like to invite professor Hoogland, dean of the faculty of science to officially invest professor Veltman with this dignity.