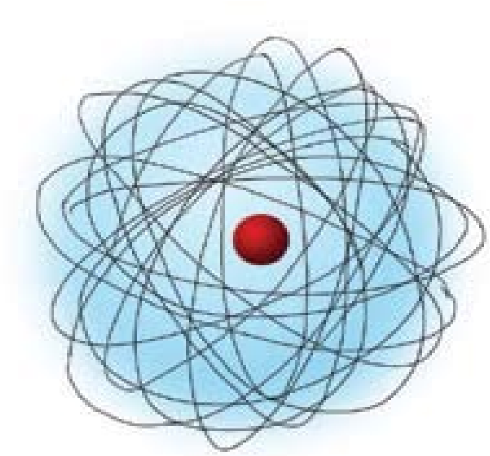
In Search of the God Particle

By Eilam Gross

The extraordinary experiment being conducted in CERN (the European Organization for Nuclear Research), in Switzerland, aspires to bring us closer than ever to the moment of Creation – the Big Bang, when the elementary particles making up the Universe were created. Billions of dollars have been invested into this quest to find out where we come from and where we are going.

About 14 billion years ago – 13.7 to be precise – the Universe was born. It emerged from a singular, energy-laden point in an event we know as the Big Bang. An updated Bible would begin with the verse: “In the beginning there was nothing. And God said: Let there be light. And there was a Big Bang, and there was space and there was time, and there was the space-time.” At the moment, no one knows what really happened during that initial infinitesimal fraction of a second of creation. We are quite certain though, that the immense energy of that moment gave rise to the conditions necessary for the creation of matter and forces, thus initiating a long process that eventually led to the existence of humans with the ability to apply our intelligence to deciphering the elements that are the building blocks of our own creation.

In 1900, 108 years ago and almost 14 billion years after the Big Bang, a 76-year-old Lord William Thomson Kelvin stood in an auditorium filled to bursting in the British Royal Society and gave one of the most famous lectures in the history of physics. In his lecture, Kelvin predicted the imminent demise of physics as a science. He claimed that two dark clouds were overshadowing 19th century physics, and if only they could be solved, physicists would have no new discoveries to make. The first of Kelvin’s two “baby” dark clouds was physicists’ failure to demonstrate the existence of ether – the medium through which light waves were believed to propagate; the second was their failure to explain black body radiation, the same radiation that causes the greenhouse effect and that prevents us from being able to sit in a car with the windows closed in summer.



Electron in jail. *The radius of the electron in the atom is on the order of a millionth of a human hair. If the electron was heavier, its "living space" would be smaller, and vice versa. A heavier electron would mean a smaller atom; the scale of the nucleus would equal the scale of the atom, and all chemical and inter-molecular dynamics as we know them would be disrupted. Lighter electrons would produce big, loose atoms, and water would evaporate even at relatively low temperatures. The electron has exactly the right mass for life to exist.*

If Kelvin were to give his lecture today, he would probably be eulogizing 20th century physics, claiming that there is but one dark cloud hanging over particle physics. Once resolved, we'll be left with nothing more to investigate as far as matter's fundamental structure is concerned. His unresolved question would be: ***How do elementary particles get their mass?*** For we 21st century physicists, the answer to this question is essential for piecing together what took place immediately following the Big Bang, and for understanding the Universe as it's described in the widely accepted Standard Model.

Needless to say, the two "dark clouds" of the 19^{th} century gave rise to modern physics' two most important theories: Einstein's special relativity, according to which energy is equivalent to mass; and quantum theory, which states that light is composed of discrete energy packets (quanta), or particles, known as photons. The answer to the "dark cloud" overshadowing research today – How do elementary particles get their mass – will undoubtedly lead to another huge leap for physics and for our understanding of the Universe. If one good reason is needed (and there are, of course, many) to justify the fact that the best physicists have flocked to CERN and billions of dollars have been pumped into the most expensive experiment in human history, it is to answer this very question.

Why is this question so important? What have we done to answer it? What is the Higgs particle and how would the CERN accelerator confirm its existence, thereby solving the riddle of the source of particle mass? What will become of the Standard Model of particle physics if this particle is not detected? Come join me on a journey through the things that engage the restless minds of particle physicists.

Components of the atom – the key to nature's secrets

In physics, as in other fields of science, if researchers find a theory convincing (due to its beauty, coherence, ability to predict known phenomena, innovation, etc), it becomes the dominant paradigm. It is the prediction power of a theory that makes it most attractive to scientists. A theory that predicts a specific outcome, which can be either confirmed or refuted experimentally, has the power to draw the best minds, and they will wait for the chance to perform experiments to test the theory. Thus, Einstein had to wait for Eddington's famous 1919 experiment, the results of which were predicted in his theory of general relativity, proving beyond a doubt that gravitation causes light to curve.

The largest project in CERN will be an experiment aimed at confirming, or rather at finding the ultimate proof, for the sophisticated edifice that modern physicists have erected to describe the creation of the Universe. This is “the Standard Model” – the common ground most physicists base their work on. As far as they are concerned, this model correctly describes the particles and forces at work in nature.

To understand the underlying principles of the Standard Model, we need to travel back in time, but this time a mere 2,500 years. The atom, or átomos in Greek, was envisioned by the ancient Greek philosopher Democritus, who described an atom as the tiniest possible particle – one that’s indivisible into smaller particles. This basic idea held until the end of the 19^{th} century, when J. J. Thomson discovered the electron. It then became clear that the atom is much more complex than previously believed – made up of components whose interactions determine its properties. That moment marks the beginning of the modern physics that deals with unraveling atomic structure, breaking atoms down in order to understand how their elementary components work together to create matter’s basic structures.

Most of us were taught in school that an atom contains a positively charged nucleus made of protons and neutrons – the elementary particles around which negatively charged electrons trace circular orbits. But this is not the case. First of all, protons and neutrons are not elementary particles, but are themselves composed of tinier particles called quarks. Secondly, if an electron flew around in circles, it would emit energy, causing its orbit to get smaller and smaller until it eventually fell inwards into the nucleus. But if the electron doesn’t fly around in circles, nor collapse inwards, then where exactly is the electron in relation to the nucleus?

Nobel Prize laureate Murray Gell-Mann took the name “quarks” from a passage in James Joyce's book Finnegan’s Wake.

Quantum mechanics revealed one of the secrets of the universe: the uncertainty principle, which states that it is impossible to accurately know both a particle's speed and location at the same time. This uncertainty decreases as the particle's mass grows. This is why we do not experience this uncertainty in our day to day lives. Our mass is immense (infinitely heavy, from the point of view of an atomic nucleus), and that's why we know exactly where we are. But electrons are so light, they're nearly without mass (the electron is 2,000 times lighter than a proton, or a hydrogen atom), and so we cannot pinpoint its location around the nucleus. All we can say is that electrons are confined somewhere inside a sphere the radius of a millionth of a human hair.

To illustrate an atom's structure, we can imagine enlarging it until the nucleus is the size of a bean. With its bean-sized nucleus, the entire atom is now as big as a soccer stadium, and the electron is a flea-sized spectator frantically whizzing around somewhere in the stands. In other words, the atom is basically empty. This both results from, and is clear proof of the uncertainty principle of quantum mechanics.

The moment God gave electrons mass, he made atoms possible, and these enabled matter to exist and stars and galaxies to bloom. With this mass, He fixed the basic emptiness of matter and established life's chemistry. The exact mass of an electron is the key to the stability of the physical-chemical system in which we live.

According to the Standard Model, in the beginning the Universe was amazingly symmetrical. All particles were massless, and a single force acted between the particles of the Universe. Order reigned. But there's no place for us in such a symmetrical universe. For matter and life to come into being, this symmetry had to be broken. And indeed, very soon after matter was created (a very, very short time after the Big Bang) the symmetry was broken, and electrons and quarks became massive – that is to say, they acquired mass. It is because of this mass that we are here today.

We started this journey with the question: How do elementary particles get their mass? According to the prevailing theory, this breaking of symmetry made it possible for the particles to have mass, and this act involved a field, which has been named after the British physicist, Peter Higgs. The particle created by the Higgs field is called the Higgs particle. This particle must exist if our current understanding of the composition of forces and particles in nature is correct. Experiments conducted in recent years have yielded circumstantial evidence for the existence of this particle. The CERN experiment is meant, among other things, to create this particle out of energy inside an accelerator, and to try and "observe it" using detectors.

Although the British scientist Peter Higgs gave his name to the Higgs field and Higgs particle, at least two other physicists, François Englert and Robert Brout, had a part in the discovery. All three were awarded the prestigious Wolf Prize by Israel's Knesset in 2004. Higgs boycotted the ceremony for political reasons.

Because of the Higgs particle's important role in this theory, Nobel laureate Leon Lederman bestowed it with the pretentious nickname "the God particle". But most physicists disapprove of this nickname, not only for its pretentiousness but because it has religious connotations. In this article, I use biblical terms and refer to angels purely for literary purposes. I believe the physics of the Universe is amazingly beautiful, and there is nothing wrong with resorting to poetry to help those who are more inclined to the humanities and the spiritual to relate to it. I believe this was Lederman's intent when he first coined the expression.

***The empty atom**: If we imagine the atom's nucleus to be the size of a bean, the atom itself will become the size of a stadium, and the electrons will be like tiny fleas whizzing frantically somewhere around the stands. We are, in fact, mostly composed of vacuum, and the proportion of vacuum to matter is dictated by the electrons' mass.*

According to the Standard Model, a moment after the Big Bang, following the great primordial vacuum and under unimaginable temperatures, particle-anti particle pairs as well as light particles called photons were born out of quantum fields. A billionth of a second later, the Universe started cooling down and chilling out, and the elementary particles we know today – electrons and quarks (the building blocks of protons and neutrons) appeared. These particles were massless. For them to acquire mass, the Universe's symmetry first had to be broken. The Higgs field, then, was the agent of this symmetry breaking. As electrons and quarks interacted with this field, they gained mass. Protons became stable and united with neutrons and electrons to create atoms, mainly hydrogen and helium. Out of these atoms, the galaxies and the stardust we are made of were created.

Fields and the creation of particles

But what is the Higgs field? Let us delve a bit into the process that took place, and try to understand the concept of a field a little better. An electron somewhere out there in our stadium stands can feel the electrical force exerted by the atom's nucleus. It's as though the spectator can make out the tiny bean in the center of the playing field. Does the electron use some kind of binoculars? Actually, it doesn't "see" the bean. A better analogy is that it is captured in a web woven by the bean.

In physics, we refer to this web an electric field. The nucleus produces an electric field that can sense anything near it and exert a force on it. Every physics major learns about this electric field, but most don't really understand it. To illustrate, think of a room with a lit heater sitting in its middle. We can map the temperature throughout the room using a thermometer. This temperature function, or map, is the temperature field. It has a value in any spot we choose in the room.

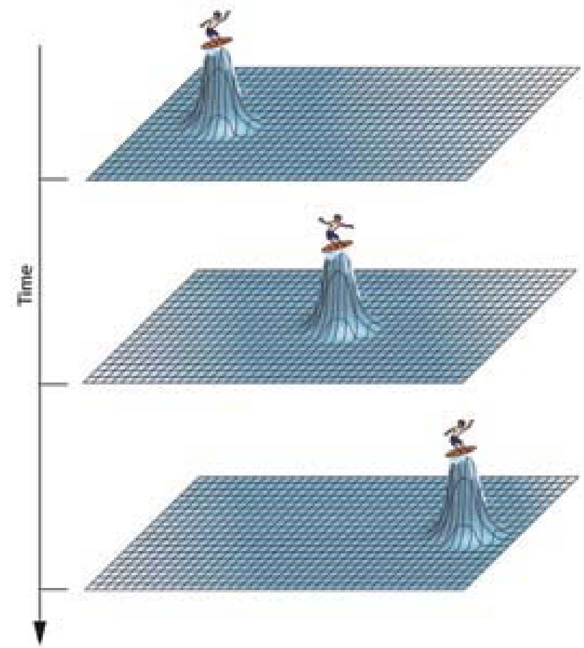
Sea level is also a kind of field. When the ocean is calm, the field has a constant value. In such a field, entering the water can be fairly boring, especially for the surfers among us. But if a boat passed us by, generating waves – a disturbance in the field – the water level would move up and down. This disturbance in the sea level field would quickly race toward us, and we would be able to ride that wave all the way to shore. The ocean's water content hasn't changed, but the disturbance in sea level carries energy with it: It's like a big ball rolling our way that pushes us along with it.

In much the same way, a disturbance in an electric field produces an electromagnetic wave. This is what happens in a broadcasting antenna – an electron moving back and forth in the antenna generates an electromagnetic wave, which expands outward to be received by our radio receiver. A water wave propagates through the motion of water molecules. But how is an electric field generated, and how does the electromagnetic wave move? What collides? What flows? In which medium does it propagate?

It took a few centuries and the work of more than a few geniuses (Maxwell, Einstein, Dirac and Feynman, to name a few) for us to realize that electromagnetic waves don't need a medium in which to propagate (Einstein's special theory of relativity) and that light is made of particles, or photons (quantum mechanics). And when special relativity married quantum mechanics, they gave birth to the concept of "quantum fields". Quantum fields are spread out throughout space-time, and they are disturbed by field excitations, thereby creating or eliminating particles. In an electromagnetic field, these disturbances are no more than energy-bearing photons. Each electron can communicate with other electrons via photons. In physics, we talk about an interaction between force particles (photons) and matter particles (electrons). In the case of the atom, photons communicate between the protons in the nucleus and the distant electron.

Quantum field theory has solved the conundrum of the distant spectator (the electron), who can see the bean in the middle of the stadium. The electron "sees" the nucleus via photon exchange in an electromagnetic field.

Poetically, one may say that when God created the Universe, he also created guardian angels, to make sure symmetry and stability were maintained. These angels – photons – are everywhere in the Universe, and wherever they sense the slightest deviation from symmetry, they emend the situation straight away. In order for them to be able to reach everywhere in the Universe and conserve symmetry, their field of action must be infinite, and so they must be massless.



Fields and particles: *No one has ever seen a fundamental particle. Intuition may be misleading: A particle is nothing like a rigid sphere with finite dimensions. A particle is a disturbance, a field excitation, moving through space-time. It's like a water wave moving in an ocean all of its own. Electrons, for instance, are actually excitations in an electron field in various places and times. Photons are excitations in a photon field – that is to say an electromagnetic electric field. A photon's movement from one place in space-time to another is called electromagnetic radiation.*

However, for our Universe to exist, it is **crucial** that many particles have mass. Elementary particles' masses determine the range and nature of forces, define the size of atoms and nuclei, and set the conditions for the chemistry of atoms and molecules. It's impossible to overstate the importance of the mechanism that endows elementary particles with mass. This mechanism is also indirectly responsible for the preponderance of matter over antimatter. It occurred at a certain moment in the creation of the Universe, thanks to a field called the Higgs field, whose excitation (the disturbance moving through the field) is called the Higgs particle.

What fascinate physicists about this mechanism – to the point of investing many billions of dollars in the Higgs particle detection project – is its theoretical beauty, as well as tantalizing experimental evidence pointing to its existence. The Higgs field allows both matter particles (electrons and quarks) and the photons that carry the radioactive (weak) force – named W and Z – to have mass. The W mass is predicted by the Higgs mechanism, and it is thus a piece of circumstantial evidence for its existence.

Mass was given to particles without explicitly breaking the symmetry of the very laws of physics that determine forces. I admit the sentence I just wrote is confusing. Its mathematical account is fairly simple, but its explanation and ensuing philosophical or intuitive significance are complex and hard to understand.

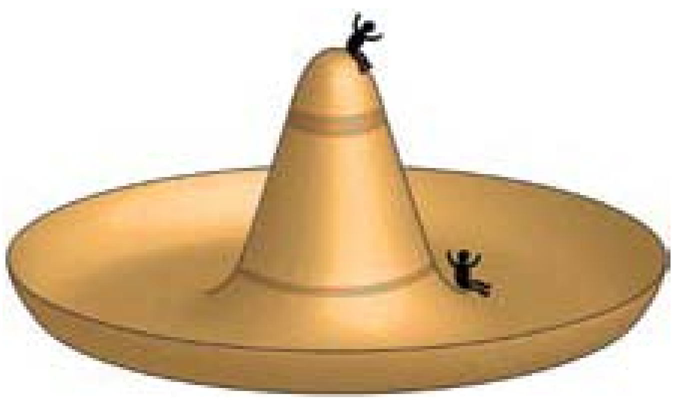
The 2004 Wolf Prize scroll states that the prize was awarded to Englert, Brout and Higgs "for their pioneering work that has led to the insight of mass generation, whenever a local gauge symmetry is realized asymmetrically in the world of sub-atomic particles." When I asked why the wording was so vague, I was told that otherwise it wouldn't look serious…

The sombrero

When I asked Francoise Englert to help me explain the Higgs mechanism to a lay audience, he spent over half an hour looking for an explanation, but in the end, he failed to find one. I hardly dare to try my luck where greater men have failed, so I will just try to present the traditional explanation nicknamed the "Mexican hat or sombrero interpretation." If you can't follow the explanation, feel free to simply skip it and rejoin us in the next chapter.

When looking at a sombrero from the top, one sees perfect symmetry. A little man perched on the tip of a sombrero looking down would see nothing but absolute symmetry. His balance is fragile there at the top, and the slightest disturbance would make him slide right down to the sombrero's rim. The laws of mechanics have no preferred direction, due to their symmetry, and so it is impossible to predict in which direction the man would slide.

The moment that balance is lost, say if the hat shakes for a fraction of a second, the man will find himself somewhere on the rim. And suddenly, although the same laws of physics that made him fall are still as perfectly symmetrical as ever, that person will no longer be in a symmetrical state. He inadvertently, but inevitably chose a particular direction out of all the possibilities, and now when he looks sideways or up, he will see something different in each direction. We can say that his symmetry was spontaneously broken.



Spontaneous symmetry breaking: *Looking from the top downwards, a sombrero has a perfectly circular symmetry. This symmetry breaks when the little man at the top slides down, landing somewhere on the rim. The laws of physics that apply to the man on the top have no directional preference, because of the hat's symmetry, and so it is impossible to predict in which direction the man will fall. The Higgs field, at its lowest energy level (represented by the hat's rim) has a constant non-zero value (the hat's radius, or the man's distance from its center), thanks to which elementary particles have a non-zero mass, while the laws' symmetry (the hat's circular symmetry) is still maintained.*

The laws of physics are still symmetrical, but the system's ground state, in which the man at the bottom of the sombrero is stable with minimal energy, no longer represents the symmetry of the law that disturbed the system's balance (made the man fall down).

Imagine now that every point in the space-time we live in contains such a sombrero. The elevation of the little man atop the sombrero, who stands for the Higgs field (the "God field"), represents the field's energy, while his horizontal location on the hat (the radius, or his distance from the sombrero's center) represents the intensity of the field.

At the moment of creation, the Universe has immense energy and unimaginable temperatures. The man on the sombrero feels uncomfortable. He rocks back and forth, left and right, looking for a convenient place to slide down the hat from, but he can't find one. The incredible temperatures keep him at the top of the hat. In this state, the mean field intensity is null, but the energy is high.

The Universe then starts cooling down, and less than a billionth of a second after the Big Bang, the man manages to slide down, coming to rest somewhere on the hat rim. At this point, the Higgs field has minimal energy, but its intensity is constant and non-zero, which means its presence can be felt. The symmetry of the laws of nature has been kept, but nature's initial state (at the top of the sombrero) has lost its symmetry. The symmetry was spontaneously broken when the Higgs field chose a certain direction, as it gained a constant, non-zero intensity. To complete the picture, we must note that the Higgs field has a weak (radioactive) charge, which enables matter particles, such as electrons and quarks, to feel the non-zero field value and acquire mass. Particles missing a weak charge are indifferent to the Higgs Field, and that's why photons, for example, remain massless (and the law of electric charge conservation is preserved), while the W and the Z – the weak force mediators that carry a weak charge – acquire mass. Moreover, since the Higgs also has a weak charge, it is absorbed into itself, feels its own existence and gives itself mass, whose value, incidentally, is still a total mystery to us.

And so, the Higgs field, which selected a certain direction for itself, with a non-zero intensity in its basic state, gave mass to the W and Z weak force photons (thus limiting the weak force's range), to the electrons (thus enabling atoms to interact with each other and chemistry as we know it to exist), and to quarks (thus giving them the mass required for proton stability). If the Higgs field ever lost its intensity, which is constant over space and time, all particles would become massless again and the Universe as we know it will become an impossibility. **The Higgs field is, therefore, another guardian angel, giving elementary particles the mass required for the Universe – including us – to exist.**

Putting the pieces together

This mechanism for granting mass by breaking symmetry was first discovered in the 1960s. It predicted the masses of W and Z, the weak force carriers, and these were indeed discovered in 1983 – having exactly the mass predicted. And it is this same mechanism that predicts the existence of the mysterious Higgs particle.

I would like to mention here a popular analogy – one that I personally don't particularly like. In 1993, the British Minister of Science challenged the British scientific community, promising a bottle of vintage champagne to the scientist who could, on the back of an envelope, explain to him what the Higgs particle was about and why it was worthwhile pouring billions of dollar into an attempt to discover it. David Miller had the winning explanation. In his analogy, the Higgs field and its excitations – the Higgs particle – is like a crowd of people filling a hall (in other words, the Universe). A famous personality, say the former Prime Minister (or a particle such as an electron), walks into the hall. Before anyone sees him, he can walk quickly and lightly. The people in the hall move closer to see him and be near him, thus surrounding him with a bubble of motion. His movements then become slow and heavy – in this sense he has acquired a mass, because the greater a body's mass, the harder it is to change its present situation. The more "famous" the particle that walked in, the stronger the Higgs field will hold on to it, and the harder it will be to move. In much the same way, the Higgs field can also be thought of as a fluid that fills the Universe. The free motion of particles moving in this fluid is hindered by the fluid's viscosity, and so they acquire a mass.

To summarize the model I described above, the Universe was created out of electrically and radioactively (weakly) charged matter particles, all massless, and they hold on to each other through the actions of massless force particles – photons. A spontaneous breaking of symmetry gave mass to both matter particles – electrons and quarks – as well as weak force photons – W and Z – and all without explicitly violating nature's symmetry, which then became "hidden".

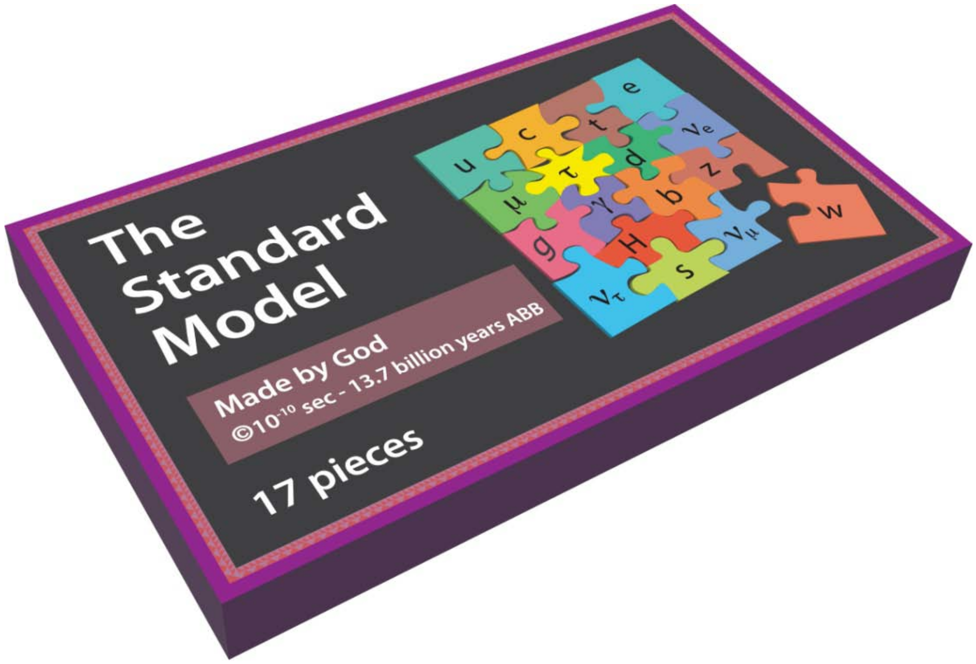
Our model is built of nature's building blocks, which are, in principle, all matter particles: six quarks, three electrons and their neutrino counterparts, the photon, W, Z, the gluon (guardian angel of the strong nuclear force, the color force. See the illustration "quarks in prison."), and last but not least - the Higgs particle. Together they compose a 17 piece jigsaw puzzle; the pieces are the building blocks of the Universe in which we live. The particles' properties, masses and various charges all act as a sort of "genetic code" for all the interactions that occur in the Universe, in which the various matter particles communicate with each other through the various force photons.

The trouble started when we tried to put the pieces together and found there was one missing. We all looked for the missing piece in the puzzle box, but we couldn't find the one that says H – Higgs. Our theoretical model was left incomplete. We physicists decided that there was nothing left to do but call the puzzle manufacturer and ask for the missing piece. The box said that the puzzle was a product of the first tenth of a billionth of a second after the Big Bang, and it seemed it was impossible to contact the manufacturer. We had no choice but to try to recreate the missing piece by inventing a process that may simulate the fraction of a second after the Big Bang.

A tunnel was built in Geneva, Switzerland, thanks to international cooperation and funding, in which thousands of scientists would work to create an environment as close as possible to what the Universe was like a tenth of a billionth of a second after the Big Bang. In this environment, they hope to create the missing particle.

Seeing Higgs

To “see” the Higgs particle, it must first be created through its field out of energy, and only then detected by a particle detector. The simplest particle detector you know is yourself – or more precisely, your eye. The eye detects light photons: It absorbs them and transforms them into signals, which later reach your brain to be processed into an image.



Made by God, 0.0000000001 sec AB ©

The Standard Model puzzle was manufactured a tenth of a billionth of a second after the Big Bang, including its missing piece - the Higgs particle.

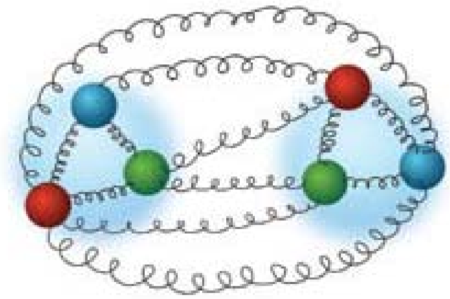
The Standard Model puzzle: *A puzzle simple enough for any kid to piece together can be made out of all elementary particles – but one piece is missing!*

There is no fundamental difference between our eye and the detector constructed in Geneva for discovering the Higgs particle, except for the fact that the latter is far more sophisticated than our eyes, since it can detect much more than visible photons. The Geneva detector is a kind of bionic eye.

The name LHC - Large Hadron Collider - refers to protons, which belong to a group of particles called hadrons

Particles are detected by this bionic eye, whose job it is to discover – in addition to photons – quarks, gluons, electrons, muons (heavy electrons) and so on. Detection is performed by transforming the whizzing particles' energy into electronic signals, which are then sent to a computer. In order to transform their energy into signals, particles are detained and absorbed by the detector (apart from the muon, the only particle that leaves a trace only until it leaves the detector,; and the neutrino, whose presence cannot be felt at all). Stopping these highly energetic particles requires an immense detector, measuring 50 meters in length and 25 meters in height (about the size of a seven story building).

The reason we haven't yet discovered the Higgs particle is that creating it requires an energy input that's at least at equivalent to its mass, and for the results to be believable; we must create quite a number of them. The fact that we haven't been able to detect it before indicates that it is heavier than the energy equivalent limitations of past experiments.



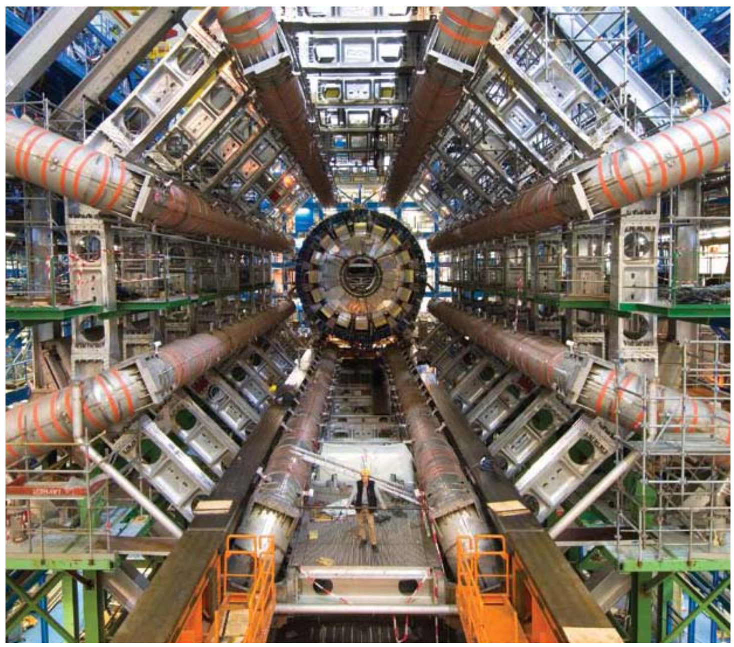
***Quarks in prison**: Each proton is composed of three quarks, and these bear what's known as a color charge: red, blue or green. The quarks cling to each other by exchanging gluons – the guardian angels that ensure protons are always white (red+blue+green = white). Since gluons also bear a color charge, they restrict proton quarks, and thus quarks cannot be found in a free state. Through gluons, one proton's quarks interact with another's, creating attraction. Gluons are therefore responsible for the strong attraction between protons, which is ten times greater than their electric repulsion .Gluons' immense bond energy, when they react with each other, is also responsible for most of the protons' and neutrons' mass.*

This is why thousands of physicists have flocked to Geneva to build the LHC – a new type of particle accelerator – a proton accelerator. Protons are 2,000 times heavier than electrons, which is why a collision between two protons is much more intense than a collision between electrons. If a collision between electrons could be compared to a bicycle accident, proton collisions are like two huge explosive-laden trucks ramming into each other head-on on the freeway.

The chances a Higgs particle will indeed be created when two protons collide are 1:1000000000000, or one Higgs particle per trillion collisions. Therefore, if we want to detect the Higgs particle, we must create trillions of proton collisions, with sufficiently high energies to create them.

Two detectors have been built for Higgs particle detection at the LHC: CMS and ATLAS. Israel is part of the ATLAS team, and although this article is general in its scope, examples and images used here come from the ATLAS detector.

Since protons are so small, it's practically impossible to aim them at each other. To increase the probability of a collision, a proton beam composed of bunches of nearly a trillion protons each will be employed. Such a bunch would look like a pin 7 cm long and 15 microns across – the thickness of a hair. Eventually, a billion protons will be colliding with another billion protons every second.



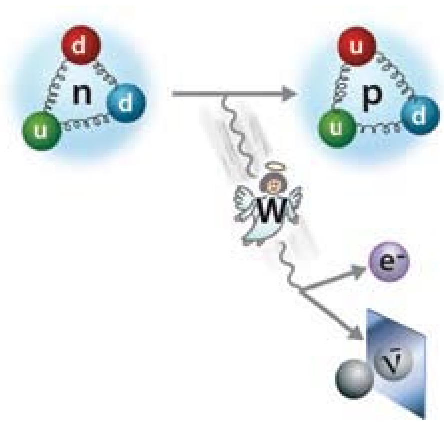
The ATLAS detector in the first stages of construction. *One can see the huge octagonal magnet enveloping it. The magnet's job is to bend muons (heavy electrons) that leave the detector, in order to measure their energy. Image: CERN*

ATLAS control room*. Prof. Giora Mikenberg of the Weizmann Institute of Science, Israel, Head of the Israeli LHC team, is thrilled by the first recorded event. ATLAS control room. Image: CERN*

This is a huge number. Just to illustrate, if a proton were a person, half the world's population would be colliding with the other half every three seconds. These billions of protons will be carrying immense energy – 7,000 times larger than the proton's mass. The energy involved in such a frontal collision should be enough to easily excite the Higgs field and create a Higgs particle.

Theoretically, when a Higgs particle is created, its mass is so large that its great energy makes it break up into smaller particles. That's why it is expected to immediately break down into heavy quarks or weak force carriers - W and Z (which themselves further break down to form quarks, electrons and muons – heavy electrons). A detector was built around the collision point, and its purpose it is to detect the products of these collisions and convert their trajectories into electronic signals, which are then sent to a computer as bytes, and further transformed into images that a skilled physicist can interpret to identify the signature of a decomposing Higgs particle.

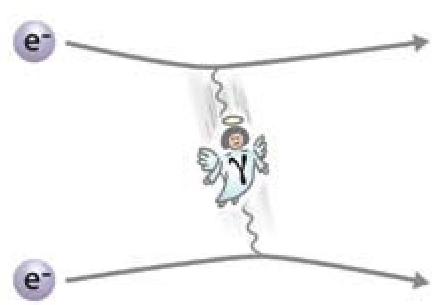
If we could, we would register the data produced in each and every of the billion collisions that occur every second, to later analyze it. However, this would be inefficient (data analysis takes a long time), as well as technologically impossible. The data processor and detector – built using what was state of the art technology only a few years ago – can register up to 300 MB a second (the equivalent of a CD every 2 seconds). If we transform these bytes into collision information, that would be 200 collisions a second. This means we're bound to lose over 99.9998% of all collisions. The immediate challenge is, therefore, to keep from losing the Higgs-containing collisions or any other collision that may be scientifically interesting.



The Higgs particle - a guardian angel: *Neutrons differ from protons in their quark composition. While neutrons are made up of two d quarks and one u quark, protons are composed of two u quarks and one d quark. The tiny 0.2% mass difference (neutrons are slightly heavier), arises from the difference between u and d quark masses. Quarks have a mass thanks to the Higgs field. Had the d quark not been slightly heavier than the u quark, protons would not have been stable, but would rather have decayed to become neutrons, and we would most probably never have come to exist. The Higgs field maintains this crucial mass difference. The process defined by nature is the radioactive one.*

A free neutron decays in about 13 minutes to produce a proton, an electron and an anti-neutrino. The delay in decay is due to the mediator of the radioactive force, the guardian angel of weak symmetry (which does not distinguish between *neutrons and protons) – the W – which is massive, so that the scope of its interaction is smaller even than the dimensions of a nucleus.*

In order to avoid such losses, the first element in the particle detector is a secondary detector system, whose job it is to quickly discard uninteresting collisions and to activate the primary detection and computing system only for interesting or potentially Higgs-containing collisions.



The law of conservation of electric charge*: Photons are the guardian angels in charge of symmetry conservation. In modern physics, the electric force between two electrons is carried by photons, whose job it is to conserve the symmetry. Any conservation of symmetry in nature invokes a conservation law. In this case, it is, naturally, the electric charge which is being conserved.*

Part of the trigger system for detector activation and data registration was developed and built in Israel, and exported to CERN. Even if Israel's contribution is only about one percent of the entire detector, it is a very important one percent, and we can and should take pride in it.

The Israeli detector was built by a team of scientists from Tel Aviv University, the Technion – Israel Institute of Technology and the Weizmann Institute of Science. An as yet unprecedented budget was dedicated to this project by the Planning and Budgeting Committee and the Israel

Science Foundation, the Israel Academy of Science, the Israeli Committee for High Energies (and the Ministry of Industry and Science.

Epilogue

But what's in it for us? What happens if we don't find the Higgs particle? This kind of question is being asked everywhere – both discreetly and openly. One must remember it is basic science we are talking about. Scientists find themselves fully rewarded for their efforts by the mere contribution they make to human knowledge and to our understanding of the structure of the Universe, its laws and components. However, funding governments and agencies would like to see some more practical benefits as well. No one can really tell exactly how much building the LHC has cost. We're talking several billions of US dollars, not including the cost of personnel. When funding such a huge project, it is quite natural to want to know "What's in it for me?" and also "What if we don't find anything?"

In 1897, when Thomson discovered the electron and was widely criticized for searching for such a useless particle – one too small for anyone to ever see – he celebrated his discovery with a toast "to the useless electron." Is there anyone around who still questions the importance of that discovery? Where would we be today if it weren't for the electron and everything that followed? Basic science doesn't often yield immediate results. Decades may pass before we realize what a discovery really means, not to mention what it can be used for. But that, of course, is icing on the cake, following the immediate benefit we get from expanding our knowledge.

At any rate, the search for the Higgs particle has already born many fruits, even though the particle itself hasn't been discovered yet. In 1990, Tim Berners Lee, a British scientist working at CERN, invented the WWW and its underlying http, while working to improve computing in general, and the data transfer protocol in particular, for actual and future CERN Higgs search experiments. Right now, about 4,000 scientists take part in Higgs experiments. It would be hard to imagine them all participating without the use of the internet.

It is very hard to answer the second question: What would happen if we don't find the Higgs particle. Most physicists working on the experiment don't even worry themselves with this question. For them, the mere fact that the Standard Model, which includes the Higgs particle, has already made other predictions that were borne out experimentally is enough to prove its existence beyond a doubt. Moreover, the mass of the weak force carriers, W and Z, which were discovered over 25 years ago, is seen as a kind of shadow trace the Higgs particle casts on the Standard Model's light. Could we be seeing a shadow with nothing to cast it?

Other physicists are certain that, Higgs or no Higgs, new particles and interactions as yet unknown to us will be discovered in the experiment, and these will provide us with new understanding and ability to predict.

I belong to the ranks of those who are convinced that within a matter of years the Higgs particle, at the very least, will be discovered. Otherwise I wouldn't have spent the last twenty years searching for it. And why do I say "at the very least"? Because if we take a close look at the Standard Model puzzle, we may see that the pieces fit nicely together, but there are still tiny gaps between them. If we use a strong microscope (such as the LHC) to look at the pieces themselves, we might discover they are composed of even tinier building blocks. That's why many scientists believe the Higgs particle discovery will be only the very tip of the iceberg.

Just as spaceships and long-range telescopes – which have seen to the ends of the Universe in recent years – send us quantities of data we'd never imagined in our wildest dreams, there's also the likelihood that soon an entire particle carnival will be discovered through the Higgs experiments, even before the guest of honor appears.

And yet? If we don’t find it? There’s no easy answer. The Standard Model will be in serious trouble. Theoretical physicists will have a lot of rethinking to do, and we experimentalists might find ourselves facing closed doors when we return to research funding agencies asking for more money to continue studying matter’s fundamental structure. It can’t be. It won’t happen. The Higgs particle will be discovered. Mark my words.

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