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THE ELEMENTARY PARTICULATE MASS GENERATION MECHANISM

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Resumo

Massa é uma das propriedades das partículas em que se há um vácuo de conhecimento sobre. Sendo um dos mais novos assuntos a se descobrir, com uma pesquisa aprofundada desde 1960 e até hoje não se sabe muito a respeito dela. Este artigo tem como afinidade apresentar de maneira didática e acadêmica o presente questionamento: Como e por que as partículas e estruturas do Universo tem massa? Apresentando dados e artigos da ciência mais avançada que temos para discorrer sobre o assunto.

Palavras-chave: Partículas; Massa; Mecanismo de Higgs e LHC.

Abstract

Mass is one of the properties of particles in which there is a knowledge vacuum about. Being one of the newest subjects to discover, with in-depth research since the 1960s and until today not much is known about it. This article aims to present in a didactic and academic way the present question: How and why do the particles and structures of the Universe have mass? Presenting data and articles on the most advanced science we have to discuss the subject.

Key-words: Particles; Mass; Higgs Mechanism and LHC.

Résumé

La masse est l'une des propriétés des particules pour lesquelles il existe un vide de connaissances. C'est l'un des sujets les plus récents à découvrir, avec des recherches approfondies depuis les années 1960 et jusqu'à aujourd'hui, on en sait peu. Cet article vise à présenter de manière didactique et académique la présente question : Comment et pourquoi les particules et structures de l'Univers ont-elles une masse ? En présentant des données et des articles sur la science la plus avancée, nous devons discuter du sujet.

Mots-Clefs: Particules; Masse; Mécanisme de Higgs et LHC.

SUMÁRIO

1. INTRODUCTION

Since the beginning of humanity, humans have wanted to find a reason for the existence of humans themselves and everything else that exists. One of the first thoughts on what everything is made of was formulated in Ancient Greece, with the “Arché” philosophy (from the Greek; "origin"), an ancient greek concept for the Fundamental Element. One of the first philosophers to share that thought was Thales of Miletus, who had the water as his “Arché”. For Thales, everything was made out of water; if the water is put in a cubic container, it’ll take the shape of a cube, and if the same water is put in a spherical container, it’ll take the shape of a sphere. Another philosopher who had his own “Arché” was Democritus of Abdera, for him, everything was made out of extremely small structures, invisible to the naked eye, called “Atoms” (from the Greek; "not divisible"). For centuries, the idea of “Atoms” was forgotten, until 1803 with Dalton’s “Billiard Ball Theory”, which retakes Democtirus’ ideas.

The most common atom known today is made out of Protons and Neutrons (Atomic Nucleus) and Electrons spinning around it (Electrosphere). Protons, Neutrons, and some other similar structures are called Hadrons (from the Greek; "thick, robust, strong"), and the interior of Hadrons are made out of Quarks, fundamental particles.

There’s something in físics called the Standard Model and it comprehends the operation of every elementary particle of the Universe: Fermions, particles that are the structure of all Cosmos, similar to “bricks” of the Universe, and Bosons, fundamental force’s mediator particles. Quarks are in the fermions “family”, however, Quarks are also a “family” of Up, Down, Charm, Strange, Top, and Bottom particles. Furthermore, Quarks also have a “brother”, caller Lepton, which are also a “family” of particles, such as electron, muon, tau, and it’s respectives neutrinos. Bosons can be divided in: Photons - mediator of the electromagnetic interaction; W+, W-, and Z- Bosons - mediator of the weak interaction; Gluon - mediator of the strong interaction; Higgs Boson - that provides mass to the other fundamental particles; and the hypothetical Graviton particle - mediator of the gravitational interaction.

There are 4 fundamental forces in the Universe: Gravitational, Electromagnetic, Weak, and Strong. The gravitational force acts in two massive enough bodies that, after interacting gravitationally, exchange supposed gravitons, which makes them attract each other. The electromagnetic force acts in two bodies with electrical charges, like electrons, for example; in this case, after the electrons interact electromagnetically, they exchange photons, and since both electrons' charges are identical, they repel. The weak force acts, for example, in the decay of particles and having as a phenomenon the beta decay minus, a proton that after interacting "weakly", releases an electron and its respective antineutrino in which W- bosons exchange and after that the proton becomes a neutron. The strong force acts both on the atomic nucleus, overcoming the electromagnetic force to repel the protons, thereby stabilizing them, and, inside the Hadrons, keeping the Quarks together.

Quantum Field Theory describes that there are fields that permeate the entire Universe and that there are fields for everything, such as an electron field. If the electron field is not undergoing any interaction, it means that there is no electron in that field, however, if there is a disturbance/vibration in that field, it means that there is an electron in that location. This wave is specifically of the electron, since for each elementary particle there is a particular wave, so the electron is somewhere in this wave itself and according to the amplitude of this wave there is the probability of its position. There are fields of fundamental forces, but for that, it is necessary to better understand what a Force and a Field are.

For there to be Force, it is necessary at least 2 bodies, and these bodies interact with each other. Field only exists in a single singular particle, in which it interacts with itself. Therefore, when a single particle interacts with a field of any fundamental force, this particle emits and absorbs mediators of this force. Example, a singular electron, when interacting with the electromagnetic field, causes the electron to emit and absorb photons.

Suppose that it is necessary to find the mass of an atomic nucleus, simply add the mass of the numbers of Protons and Neutrons, however, this statement is only valid if the atomic system is open, that is, no interaction is taking place between the particles. Therefore, in a real system, therefore a closed system, the energy made by the strong force is relevant. According to the Theory of Relativity we have $E=mc^2$, thus, $m=E/c^2$, in this way, mass is a style of energy. This is called relativistic mass, however, a fundamental particle does not have a force that stabilizes its own structure, so the mass of these particles must come from another source.

In the past, it was not believed that fundamental particles had mass, as Gauge Symmetry described it like that, however, this became a problem, because, for the unification of Electromagnetic and Weak Forces in an Electroweak Theory, it was necessary that the mediating Bosons of Interactions Weaks were massive. So it was necessary to describe a way in which these particles have an intrinsic mass.

Peter Higgs, then, theorized the existence of a Higgs Field - which, unlike other fields, this one has energy/resistance. And that when a particle interacts with this field, it undergoes a resistance and starts to emit and absorb Higgs bosons - unlike other bosons, this one is not vector, so there is no exchange of Higgs bosons. In this resistance with the Higgs field, the interacting particle receives/gains mass.

To detect a Higgs boson, a particle collider is needed that accelerates to enough energy so that in this highly energetic collision it turns any virtual particle (except the graviton) into real, including the Higgs boson, as it interacts strongly with the Higgs Field thus being highly massive thus requiring great energies. However, in the extreme amount of particles released, exorbitant data is collected, so the internet was created to distribute all this data to research centers and universities to help in the “Boson Hunt”.

2. ABOUT THE FUNCTIONING OF PARTICLE PHYSICS

It was thought that the Universe was made out only of Atoms, but with time and scientific advances, understanding the micro-cosmos became more possible. There are dozens of particles for each Greek letter, but, currently, only 18 are fundamental particles - those that really are indivisible and elementary. They are divided into Particles that constitute matter and "messenger" Particles, those that deliver interparticle information. The "messenger" Particles are called Bosons and are responsible for mediating Nature's Fundamental Interactions, the ones that govern the function of all quantum Universe

2.1. The Principles of Atomic Models

Arché (in classical Greek: ἀρχή) is a pre Socratic term for what should be the nature's fundamental element. For Thales of Miletus, for example, the *Arché* would be the water. For Thales, everything was made out of water; if the water is put in a cubic container, it'll take the shape of a cube, and if the same water is put in a spherical container, it'll take the shape of a sphere; therefore, for Thales, everything and everyone was made out of water. Nevertheless, it wasn't just Thales who had its own *Arché;* other philosophers had their own idea of the possible fundamental element. Anaximenes of Miletus said that the *Arché* was the air; Pythagoras of Samos said it was the numbers; Eraclitus of Ephesus said it was the fire, the opposites, and the movement. Humans always had the desire to know the composition of everything, to find out what is nature's fundamental element. (SPINELLI, 2002, p. 81)

> (...) All things are differentiations of the same thing and are the same thing. And this is evident. Because if the things that are now in this world - earth, water, air and fire and the other things that manifest in this world - if any of these things were different from any other, it would be different and differentiated its own nature and if it did not remain , then it would not remain pure, and through this he discovered that many changes and differentiations had occurred, so that things could in no way mix with each other, neither do one another good or bad, nor could the plant grow out of the earth. , nor would an animal or anything else come into existence, if all things were not composed so as to be the same. All things are born, through differentiations, from the same thing, sometimes in one form, sometimes in another, always returning to the same thing. (DIÓGENES, [undated], p. 99-100).

According to Bachelard, scientific theories are always mutable, for him, we must always oppose scientific theories, so that this theory may be more updated or even substituted by a better theory, therefore, leading to scientific advancement. (MOREIRA, 2011, p. 124)

“This philosophy of no is also a philosophy of disillusionment. In other words, scientific knowledge is always the reform of an illusion, it is the result of disillusionment with what we thought we knew” (LOPES, 1996, *quoted in* MOREIRA, 2011). Therefore, new theories appeared, like, for example, John Dalton’s Atomic Model, in the 19th century, which took up the ideas of the Greek philosopher Democritus of Abdera[1] (PEREIRA; SILVA, 2015, p. 2). Dalton’s model was known as the “Billiard Ball Theory” (1803), in which his *Arché* was an extremely small structure - there was nothing smaller than it -, indivisible, and that everything was made out of it. Soon after came Thomson’s “Plum Pudding Model” (1907), the first division of the Atom, a positively charged mass with scattered negatives charges; Rutherford’s Model (1911), also known as “The Planetary Model of the Atom”; Rutherford-Bohr Atomic Model (1913), by the physicist Niels Bohr, that improved Rutherford’s model by adding the quantum theory of Max Planck[2], giving Atoms Energy levels; and Schrodinger’s Model (1926), by the physicist Erwin Schrodinger, that uses Heisenberg and Louis de Broglie’s researches to explain his Undulatory Model (LOPES, 2009, passim). Figure 1 shows the evolution of the Atomic Models.

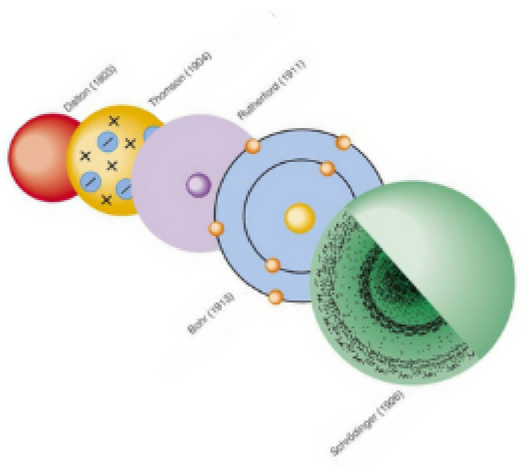

Figure 1 - The evolution of atomic models. **Source:** Stoodi.

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[1] There were other philosophers and researchers, in the centuries between Democritus and Dalton, that had great contributions to Modern Chemistry, but it won't be a topic covered in depth.

[2] Max Planck said that Energy was not like a continuous flow, he said that in fact Energy is a flow of “packages” of Energy and that these “packages” only carry natural amounts of Energy, that is, only natural numbers (1 , 2, 3,…), therefore Energy is quantized. These quantized numbers are always multiples of 6.62607004 x 10^-34, and this number is constant, so it is described as “h” and this is a Planck constant.

2.2. The Standard Model of Elementary Particles

Over time and new studies, physicists began to find more and more Particles, like, for example, the neutrinos, postulated by Wolfgang Pauli, in 1931, explaining the decay of Neutrons (LOOS, 2021) and, from that moment, they began to identify an exorbitant number of Particles, like Mesons π, π+, π-, Mesons Ks, Kl, K+, K-, Baryons Δ, Δ+, Δ-, Δ++ and countless other Particles, besides its Antiparticles[3]. The number of Particles is of such an extent that it was necessary to name a group called "Particle Zoo". Generally, it was necessary to discover the properties of a Particle or a specific Particle to explain a theory, however, after the 1930s they started to identify so many Particles that it took a theory to explain this exaggerated quantity of them. The best-formulated theory, which explains it in a clear and cohesive way, is entitled: Standard Model of Elementary Particles. Right below, Figure 2 demonstrates the Standard Model.

Figure 2 - Standard Model. **Source:** LOOS, Pedro. **The Standard Model Explained: The Best Theory of Physics**, 2021. Available at: <https://www.youtube.com/watch?v=Kn4pAoucyMg>. Accessed on: 28 Aug. 2021

The model currently contains only 18 fundamental particles, divided into categories. The first division is between Bosons and Fermions. Bosons are particles that mediate the fundamental interactions of the universe and Fermions are the ones that constitute the matter.

[3] According to the charge symmetry (we will see symmetries in chapter 3), if there is a positively charged particle, there is necessarily a twin particle with the same mass, but with negative charge, and vice versa.

The Fermions are divided into two parts: Quarks and Leptons. There are 6 types of Quarks and 6 types of Leptons, each with different properties: Quarks Up, Down, Charm, Strange, Top and Bottom; and there are Leptons Electron, Electron Neutrino, Muon, Muon Neutrino, Tau and Tau Neutrino with electrical charges[4] -1, 0 or even 1, if we count the Anti Leptons.

2.3. About Quarks

The Quarks are the ones that form Hadrons (from the Greek, *Hadros*, which means "massive", "robust", "strong"), heavier particles like protons and neutrons. Hadrons can be Baryons - containing 3 Quarks in its interior, organized in qqq or $\bar{q}\bar{q}\bar{q}$[5] - or they can be Mesons - containing 2 Quarks in its interior, organized in $q\bar{q}$. (MOREIRA, 2011, p. 67). Quarks have fractional electrical charges that can be ⅔ or -⅓, or, if referring to Antiquarks, charges -⅔ ou ⅓. Quarks can't be free, they are always inside a Hadron, therefore, the sum of quarks' charges needs to be a whole number, which can be of -2, -1, 0, 1 or 2. A Proton's charge is 1, because, inside it, there are two Quarks, with charge of ⅔ and one Quark with charge of -⅓, consequently ⅔ + ⅔ -⅓ = 1, a whole charge. (MOREIRA, 2011, p. 60).

Another property of Quarks is called **color charge**. These colors are different from the optical colors; Quarks' colors are like the electrical charge, but with other characteristics. There are, in total, 6 colors: red, green, blue, antired, antigreen, and antiblue. The sum of red, green, and blue colors cancel each other out. Hadrons are never going to have color, since the colors in their interior cancel each other out, therefore, Quarks' colors inside a Hadron are always different. Inside a Baryon, there are the three colors and, inside a Meson, there are two colors - each color with its anticolor, for example, red and antired. (PICH, 1995, p. 2). So, in fact, there are not just 12 Fermions, but 48 Fermions, 32 Quarks and 12 Leptons, including the Antiparticles.

> (..) particles normally found in nature have no color, as they are made up of several quarks, so that the three colors are mixed in equal proportions, resulting in a colorless particle. In the case of the proton, for example, the three quarks that make it up are a red, a green, and a blue so the proton itself has no color. Despite this, color plays a very important role in the theory of

[4] Max Planck said that Energy was not like a continuous flow, he said that in fact Energy is a flow of "packages" of Energy and that these "packages" only carry natural amounts of Energy, that is, only natural numbers (1 , 2, 3,…), therefore Energy is quantized. These quantized numbers are always multiples of 6.62607004 x 10^-34, and this number is constant, so it is described as "h" and this is a Planck constant.

[5] "q" means Quarks, and any particle represented by a letter with a macron symbolizes that the particle is an Antiparticle.

> the forces that hold quarks together to form the particles that are here being called usual, such as the proton. (MOREIRA, 2011, p. 25)

2.4. Fundamental Interactions

There are 4 Fundamental Interactions of nature: the Strong Interaction, the Weak Interaction, the Electromagnetic Interaction and the Gravitational Interaction, each of these interactions has its Quanta, a mediating Particle of these interactions. The Strong Interaction Quanta is the Gluon, the Weak Interaction Quanta are the W+, W- and Z, the Electromagnetic Interaction is the Photon and the Graviton Interaction is the Graviton - a Particle that has never been found experimentally. Bosons function as Virtual Particles[6], being emitted and absorbed by other Particles - with respect to Fundamental Forces; resulting in an exchange of Bosons, such as, for example, the exchange of Photons between Electrons. In Figure 3, the exchange of Photons between Electrons through Quantum Electrodynamics is shown. Sometimes there is no exchange of Bosons, but an emission and absorption of these by some Particle - in relation to the Fundamental Fields[7] (MOREIRA, 2011, p. 99).

> The theory of interactions between photons and electrons is called Quantum Electrodynamics (QDE); correspondingly, the theory of interactions between gluons and quarks is called Quantum Chromodynamics (...) Continuing the analogy between these two theories, it is observed that an electrodynamic field creates an attractive force between two objects charged with opposite charges, a which in quantum terms is created through the exchange of virtual photons between these objects, in the same way that afield chromodynamic would create an attraction force between quarks through the exchange of some particles analogous to virtual photons. Such particles, as seen, are called gluons. (MOREIRA, 2011, p. 115)

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[6] Virtual particles are particles that don't actually exist, however they have the potential to exist and they protect as a solution that there are real particles, so there are both real electrons and virtual electrons. They become real when there is a breakdown in Energy conservation due to quantum phenomena, but this lasts in an instant of time. And this instant of time has its duration provided by the Heisenberg Uncertainty Principle, which postulates $\Delta E \Delta T > h / 2\pi$, therefore, the greater for Potential Energy, the less time the Particle exists.

[7] According to Newton, Force is the product of Mass with acceleration and necessarily needs 2 or more bodies for Force to exist, unlike Fields, since only 1 body is needed for this, exerting Force on itself.

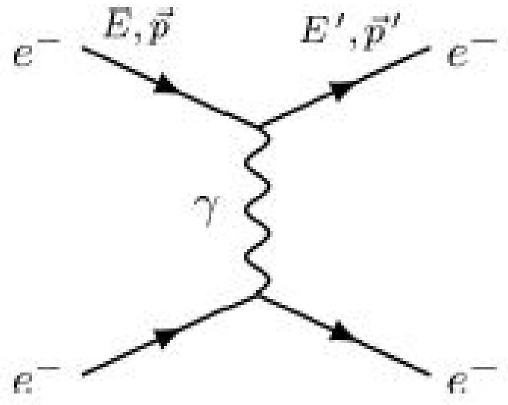

Figure 3 - Quantum Electrodynamics **Source:** Rev. Bras. Physical Education. 43, 2021. <https://www.scielo.br/j/rbef/a/7t5mJSb8rsk6TXWJXGyQY4n/?lang=pt>

Quarks interact with the Strong Force, this is the Force that allows their stability, and exchange Gluons within Hadrons and also the stability of Protons and Neutrons in an Atomic Nucleus. The Weak Force is responsible for Beta decay, the transformation of a Down quark into an Up quark within a Neutron due to the W-Boson, thus transforming into a Proton and releasing an electron and an electron antineutrino (Beta Decay minus) or releasing a positron and an electron neutrino (Beta plus decay), is also responsible for the stability of electrons in the electrosphere. In Figure 0, the Beta minus Decay is shown. The Electromagnetic Force is responsible, as well as the Weak Force, for the stability of the electrons in relation to the Atomic Nucleus and also for the attraction of particles with different charges and the repulsion of particles with equal charges, seen, for example, in Figure 4. A Gravitational Force is null in the Microcosm, but it governs practically everything in the macroscopic universe, such as planetary motion and the stability of large structures, such as galaxies and stars.

Gluons do not have Mass or electrical charge, but they do have a color charge and have the property of changing the color of Quarks and also have spin[8] 1. The Weak Force Bosons theoretically were not supposed to have Mass, they have an electrical charge, but they do not have a color charge. and they have spin 1. Photons have no mass, no charge whatsoever and they have spin 1. Gravitons are theorized with no mass, no charge at all, but their spin is equal to 2 (something extremely strange for a particle).

[8] Spin is a property of particles as fundamental as color or electrical charges and mass. The spin causes a particle to obtain a magnetic field and they can have spins "up", with the positive pole "up", or "down", with the positive pole "down". Fermions have a fractional spin, such as ½ , and Bosons have an integer spin, all multiples of $\hbar$ (Planck's Reduced Constant).

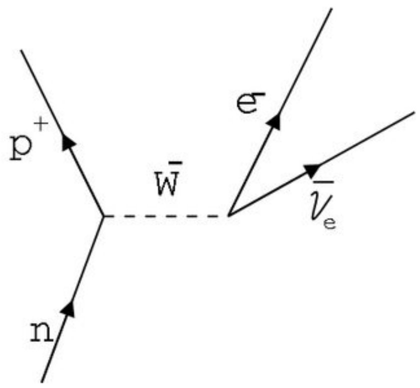

Figure 4 - Beta Minus decay. **Source:** StackExchange

2.5. Particle-Wave Duality of Mass and Schrodinger's Equation

According to Broglie, the Mass of a body is inversely proportional to its Wavelength, so a macroscopic body has an irrelevant Wavelength, while Particles have a Wavelength relevant for this phenomenon to act and, for him, since Energy behaves both as a Wave and as a Particle, Mass would suffer from the same duality, therefore, he theorized a method of analyzing Mass as a Wave. Furthermore, according to Born's Rule, the amplitudes of this Wave are proportional to the probability of the position of a Particle, that is, a Particle is more likely to be where there is a greater amplitude of the Wave, and the Wavelength refers to Particle that has it, that is, a Particle X has a Wavelength X and a Particle Y has a Wavelength Y. (FARINA, 2017). De Broglie postulated the equation:

$$\lambda = \frac{h}{K} \tag{1}$$

Which means that the Wave of a Particle depends on its velocity and that velocity is constant.

One method of identifying this wave duality of Mass and Energy is in the Double-Slit experiment, where the Particles go through two slits and these Particles spread out until detected by a plate at the end of the process, however, the detection of the plates match like a Wave passing through these two slits. Figure 5 shows the Double-Slit experiment.

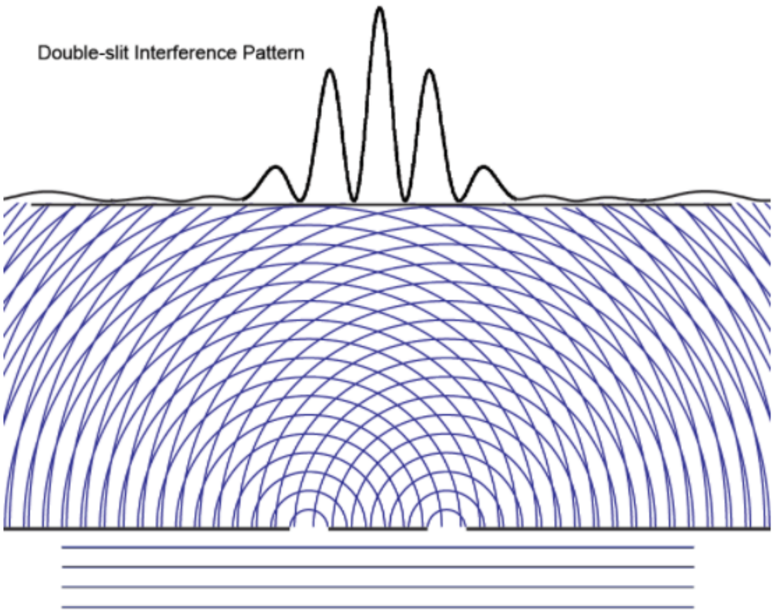

Figure 5 - Double-Slit Experiment. **Source:** Vinaire's Blog

According to Max Planck, Energy is equivalent to the product of the Planck Constant and the Frequency. However, this equation can be expressed as the product of the Reduced Planck Constant by the Angular Frequency.

$$E = h \cdot f \tag{2.1}$$

$$f = \frac{\omega}{2\pi} \therefore E = h \cdot \frac{\omega}{2\pi} \tag{2.2}$$

$$\frac{h}{2\pi} = \hbar \therefore E = \hbar \cdot \omega \tag{2.3}$$

Therefore, the Angular Frequency can be attributed as:

$$\omega = \frac{E}{\hbar} \tag{3}$$

Energy is (E) , the Planck Constant is (h), Frequency is (f), Angular Frequency is (ω), the angle of a complete circle is (2π), and the Reduced Planck Constant is (ħ).

Besides, according to Einstein's Theory of Relativity, the Particle with no mass has a Moment[9] equivalent to the ratio of the Particle's Energy and the Speed of Light.

$$P = \frac{E}{c} \tag{4}$$

As Light can be expressed like a Wave, the Speed of Light is equivalent to the product of the Wavelength and the Frequency. Energy can also be related to the Planck Postulate, therefore:

$$P = \frac{h \cdot f}{\lambda \cdot f} \therefore P = \frac{h}{\lambda} \tag{5}$$

Wavelength is equivalent to the ratio between 2π and the Quantity of Waves, therefore:

$$P = \frac{h}{\frac{2\pi}{K}} \therefore P = \hbar \cdot K \tag{6}$$

So the Wave Quantity is equal to:

$$K = \frac{P}{\hbar} \tag{7}$$

Moment is (P), Energy is (E), the Speed of Light is (c), the Planck Constant is (h), Frequency is (f), Wavelength is (λ), the angle of a complete circle is (2π), Quantity of Waves is (K), and the Reduced Planck Constant is (ħ).

Schrodinger, after studying Broglie's theory in depth, formulated Undulating Mechanics. A priori, it is worth mentioning something called the Wave Function, that for each position (x) and for each instant (t), there is an infinite set of Wave values, that such function is expressed as:

$$\Psi(x, t) = A \cdot and^{iKx} \cdot and^{-i\omega t} \tag{8}$$

[9] Moment is a physics property based on the Amount of Movement of a body.

According to (3), we have:

$$\Psi(x,t) = A \cdot and^{iKx} \cdot and^{-i\frac{E}{\hbar}t} \tag{9}$$

Just like Newton, who used differential and integral calculus to theorize the Fundamental Principle of Dynamics To mathematically write a Particle suffering a Force, Erwin Schrodinger will write the Dynamics of a Wave suffering a Force, therefore he adheres to the following calculations:

$$\frac{\partial\Psi}{\partial t} =- i\frac{E}{\hbar}\Psi \tag{10.1}$$

$$\frac{\partial\Psi}{\partial x} = iK\Psi \therefore \frac{\partial^2\Psi}{\partial x^2} =- K^2\Psi \tag{10.2}$$

Therefore:

$$\frac{\partial^2\Psi}{\partial x^2} + K^2\Psi = 0 \tag{11}$$

When analyzing a Particle without Potential interaction, it can be deduced that:

$$\frac{\partial^2\Psi}{\partial x^2} + K^2\Psi = 0 \therefore \frac{\partial^2\Psi}{\partial x^2} + \frac{P^2}{\hbar^2}\left(\frac{2m}{2m}\right)\Psi = 0 \tag{12.1}$$

$$\frac{p^2}{2m} = E \therefore \frac{\partial^2\Psi}{\partial x^2} + \frac{2m}{\hbar^2}E\Psi = 0 \tag{12.2}$$

$$E\Psi = \frac{-\hbar^2}{2m} \cdot \frac{\partial^2\Psi}{\partial x^2} \tag{12.3}$$

Therefore, the Schrodinger Equation for a Free Particle is:

$$i\hbar \frac{\partial\Psi}{\partial t} = \frac{-\hbar^2}{2m} \cdot \frac{\partial^2\Psi}{\partial x^2} \tag{13}$$

Thus, the Kinetic Energy is equal to Total Energy.

Knowing the analogy between Mechanics and Optics in Hamiltonian Mechanics[10]

$$n = \sqrt{1 - \frac{V}{E}} \tag{14.1}$$

$$K = nK_0 \tag{14.2}$$

It is possible, then, by adding these formulas to equation (11), we have:

$$\frac{\partial^2\Psi}{\partial x^2} + n^2 K_0^2 \Psi = 0 \tag{15.1}$$

$$\frac{\partial^2\Psi}{\partial x^2} + \left(1 - \frac{V}{E}\right)\frac{p^2}{\hbar^2}\left(\frac{2m}{2m}\right)\Psi = 0 \tag{15.2}$$

$$\frac{-\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + E\Psi - \frac{V}{E} \cdot E\Psi = 0 \therefore E\Psi = \frac{-\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V\Psi \tag{15.3}$$

Thus, the Schrodinger Equation for a Particle that interacts with a Potential V is:

$$i\hbar \frac{\partial\Psi}{\partial t} = \frac{-\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V\Psi \tag{14}$$

Therefore, Total Energy is the sum of Kinetic Energy with Potential Energy.

Over time it is expressed as (∂t), the Kinetic Energy of the Particle is expressed as $\left(\frac{-\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2}\right)$, the Potential Energy is expressed as ($V\Psi$) and the Wave Function is expressed as (Ψ) . The

[10] Hamiltonian Mechanics is used when there is a periodic alternation between Kinetic Energy and Potencial Energy.

equivalence to zero, in the previous calculations, is because a Kinetic Energy added to a Potential Energy makes the Total Energy null, therefore, zero. The Schrodinger Equation for a Free Particle adheres to a Photon, because Photons are not massive, unlike Electrons, which has the application in Schrodinger's Equation for a Particle that Interacts with a Potential V, since the Electron has mass. (PHYSICS Prof. Daniel, 2021; GOICOCHEA, 2014).

2.6. Quantum Field

Quantum Field Theory is one of the most widely accepted theories in Quantum Physics, as it describes the behavior of all Particles in the Universe. It predicts the existence of invisible Fields that permeate the entire Cosmos and deliver the characteristics of a Particle. For example, an Atom that interacts with the Electron Field causes the Field to have a disturbance in the amount of Wave Functions referring to the Electrons (ranging from 1 to 118); a Proton that interacts with the Quark Field causes the Field to have a disturbance in the amount of Wave Functions referring to Quarks (ranging from 2 to 3); a Lepton that interacts with the Electric Field causes the Field to vibrate in the respective charge of the referred Lepton (ranging from “e” to “-e”); a Quark interacting with the Chromatic Field causes the Field to vibrate in the respective color of the referring Quark (ranging from Red, Green, Blue and their respective anti-colors). The interaction of a particle with a respective Field generates a vibration referring to the interacting Particle and it is this vibration of the Field that delivers the characteristics of the particles. When there is no interaction in the Field in a delimited space, something called **quantum fluctuations** occurs, the greater the time variation Δt, the less certainty of the Energy variation ΔE of this Field due to the Heisenberg Uncertainty Principle[11].

$$\Delta E \Delta t \geq \frac{\hbar}{2} \tag{15}$$

When the uncertainty of the Energy of this Field becomes greater than twice the Mass of two equal Particles, a Particle and an Antiparticle are created that annihilate immediately after their creation, this is because Virtual Particles have Energy enough to become real for a

[11] Heisenberg's principle describes that the greater the physical precision for determining the moment variation, the less the physical precision for determining the position variation, and vice versa. This is also true for the Energy variation and the Time variation. Therefore, you cannot accurately measure both quantities at the same time.

brief period of time, because of the Energy Conservation Law[12], therefore. Even the vacuum is not empty, there are Particles and Antiparticles being created and annihilated all the time.

There are Fields of Elementary Interactions: an Electron interacts with the Electromagnetic Field, this makes it emit and absorb Photons, therefore, it is surrounded by a “cloud” of Photons. Inside a Hadron there are Quarks that interact with the Strongfield, emitting and absorbing Gluons, so inside a Hadron there are Quarks and a “cloud” of Gluons.

> (..) The fact is that the masses and charges of particles described by a certain theory are, in general, modified by interaction. Thus, an electron, for example, is always surrounded by the cloud of photons associated with the electromagnetic field that it creates. It is always interacting, emitting and absorbing photons. (GOMES, 2002, p. 12)

A Unified Theory of these Forces and Fields is described as a "Theory of Everything", since it would explain the behavior of all Particles in the Universe, if all these Elementary Interactions could be unified, then it could be the *Arché* ultimate of humanity.

[12]The Energy Conservation Law dictates that Energy is never created or lost, it is fixed and therefore all Energy is transformed.

3. THE HIGGS MECHANISM

Although Mass seems to be something simple and a property that all matter possesses, it is more complex than one can imagine. The Standard Model Particles were theorized by Gauge to have no Mass, however they do contain Mass, so it turned out that either there was an unknown phenomenon that allowed these Particles to have Mass, or that, at worst, the Standard Model was wrong. . Thus, in 1964, physicist Peter Higgs theorized a Mass Generation mechanism, by the interaction of Fundamental Particles in a Field, called a Higgs Field, thus emitting and integrating a mediating Particle of Interaction, the Higgs Boson.

3.1. Relativistic Mass

It is easy to think that the Mass of an Atom is the sum of the Mass of Protons and Neutrons in the Atomic Nucleus, or that the Mass of a Proton is the sum of the Mass of Quarks within it, however, these statements are mistaken since the Mass of Atoms and Protons are greater than the sum of the Mass of their interiors. ……...There is a relativity between Mass and Energy given by Albert Einstein's famous equation:

$$E = mc^2 \tag{16}$$

In which the Energy is the product of Mass and the square of the speed of light in a vacuum, which can be observed experimentally, for example , in the fission of Uranium (Figure 6) into two smaller elements. The Mass of Uranium is greater than the sum of the Mass of the minor elements, as part of this Mass was transformed into Energy. However, the following comparison can be attributed:

$$E = mc^2 \therefore m = \frac{E}{c^2} \tag{17}$$

Mass is equal to the ratio of Energy with the square of the speed of light in a vacuum, and that is where the Hadron Mass comes from and of the Atoms, because the Strong Force that keeps these structures attracted to each other is in an extremely small space, therefore, part of the Energy caused by the Strong Force is transformed into Mass. (LEMOS, 2001, p. 8).

With that, a question is opened about “where would the Mass of Elementary Particles come from?”. It is noteworthy that Energy does not behave like Mass or vice versa, since Mass is a form of Energy, Mass is Energy, an Energy undergoing a certain phenomenon. “(...) Energy is conserved. Energy doesn't transform into anything, it's just different particles that transform into each other. In other words, energy is conserved but energy carriers, and the form in which it appears, in fact, change.” (MOREIRA, 2011, p. 110). There is, therefore, a difference between the Relativistic Mass - Hadron Mass - and the Intrinsic Mass of Elementary Particles.

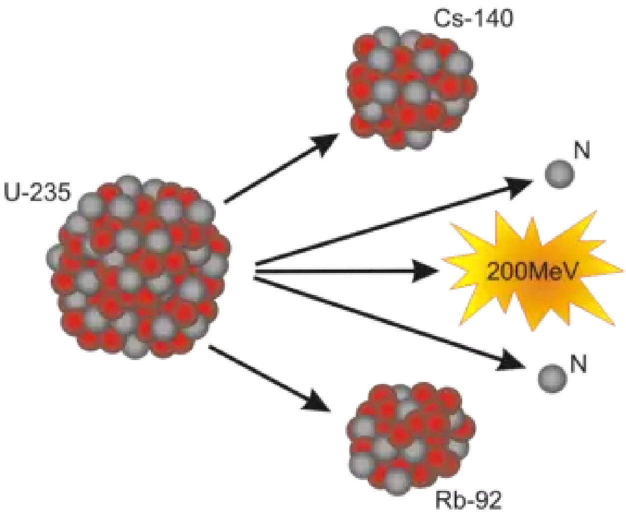

Figure 6 - Uranium-235 fission into Cesium-140 and Rubidium-92 atoms, releasing neutrons and energy. **Source:** Nuclear Energy, 2009. <https://pt.energia-nuclear.net/que-ea-energia-nuclear/fissao-nuclear>

3.2. Symmetry and Asymmetry

Symmetry and Asymmetry are characteristics or properties of a system, such as the reflection of an arrow. If an arrow pointing to the **right** is presented to a mirror, the reflected image will be an arrow pointing to the **left**. That means the system has symmetry. However, if the arrow pointing to the **right** reflects an image of an arrow also pointing to the **right, then** there is an Asymmetry in the system. In Figure 7, the symmetry and asymmetry between the reflection of arrows is presented. "symmetry is defined as the property of a system not to change in the face of any transformation and it is the invariance that characterizes symmetry" (TRZECIAK, 2017, p. 7).

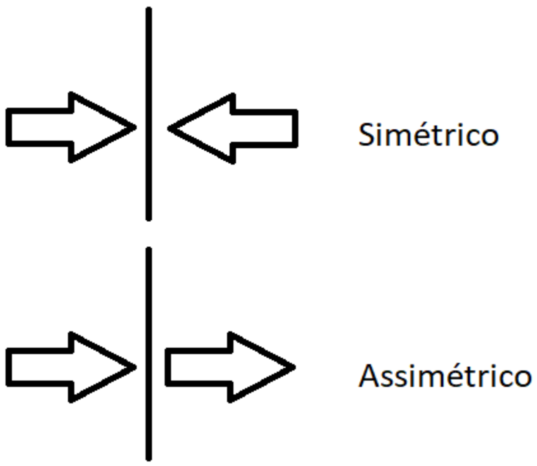

Figure 7 - Symmetry and Asymmetry between arrow reflections. **Source:** Copyright image.

There are 3 main Symmetries for the Universe regiment: Charge, Parity and Time. Call of CPT Symmetry, such that it cannot be broken[13]. A Charge Asymmetry makes that there are pairs of identical Particles, but with opposite charges, that is, pairs of Particles with positive and negative charges. An Asymmetry of Parity is the example between the reflection of the aforementioned arrows. And an Asymmetry of Time is where a reaction is different if we "go back in time", for example, assuming that a red colored Quark, over time, changes its color to blue. If we "go back in time", Quark changes its color not to its original color, but to another color, in this case, to green (MOREIRA, 2011, p. 113).

3.3. Electroweak Theory

The Higgs mechanism had its main function to explain the Electroweak Theory (the union between Electromagnetic Interaction and Weak Interaction). It is known that at the beginning of the Universe, all Interactions were unified, but from a moment on, all Interactions dissociated and Electromagnetic Interaction and Weak Interaction became different since the Universe was above surroundings 10^{15} Kelvin , approximately $1 \cdot 10^{-12}$ seconds after the Big Bang. After the cooling of the Universe, there was a Spontaneous Symmetry Break, where the Electroweak Interaction separated. However, it is possible to recreate these conditions with Particle Accelerators like the LHC.

Weak and Electromagnetic Interactions are very similar and this can be observed in the Parity Break as a function of Electrons spin, for example. Figure 8.

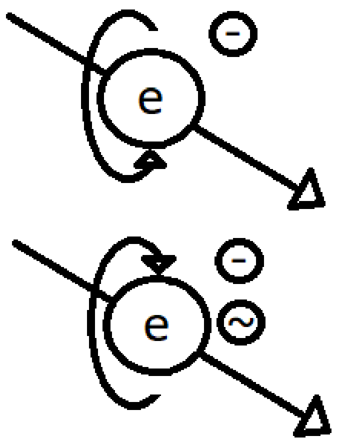

Figure 8: Parity break as a function of electron spin. **Source:** Copyright Image.

By just reversing the spin of the Electron, it makes it feel Weak Interaction (represented as [~]). These similarities with Electromagnetism lead to an Electroweak theory. (O'DOWD, 2020).

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[13] One or two of these symmetries can be broken, but never the CPT symmetry. Having an inversion break of Charge, Parity and Time can result in a total change of most quantum theories.

Also, Weak Bosons have Mass for the following factor: Weak Interaction has a short-range nature of interaction. According to the Yukawa Potential, the mediator Mass is inversely proportional to the interaction distance, as the Electromagnetic interaction distance is infinite, the mediator Mass, in this case the Photon, is null, on the other hand, as the Weak Interaction is short range, the Weak Boson Mass is relevant.
The Yukawa Potential can be described as:

$$V(r) =- \frac{g^2 \cdot and^{\mu r}}{4\pi \cdot r} \tag{18}$$

Therefore, we needed a way to explain how Weak Bosons had Mass, since the Caliber Theory or Theory of Gauge describes that Standard Model Particles have no Mass, due to the calculation:

$$i\hbar\gamma^{\mu}\partial_{\mu}\psi = 0 \tag{19}$$

When adding Mass in the calculation with Symmetry, which demonstrates the behavior of all Standard Model Particles, this calculation becomes be Asymmetric. So, it was necessary to explain this Asymmetry or the Electroweak Theory and even the Standard Model would be incorrect. “The simple requirement that the weak force be mediated by massive particles finally unified the weak force with electromagnetism and revealed the existence of Higgs particles” (O'DOWD, 2020).

There are two theories that demonstrated a “Mass Generation” due to a Symmetry Breaking phenomenon: the BCS Theory for superconductivity at low temperatures and the Nuclear Pairing Theory in the liquid drop model. , which will be exposed below.

3.4. BCS Theory for Superconductivity at Low Temperatures

In an electrical conduction, there is a relationship between Temperature and Resistance, both of which are proportional. The lower the temperature of the conductive material, the lower its Resistance will be, therefore, the electrons pass without “obstacles” through the material. But, theoretically, the Temperature and Resistance graph should be uniform and the Resistance would never reach zero. However, there is a critical temperature[14], at which the Resistance becomes zero. In Figure 9, a graph between Resistance (Ohms) and Temperature (Kelvin) is shown relating a superconducting metal to a normal metal. (CAPAZ, 2019).

[14] This critical temperature is different for each material.

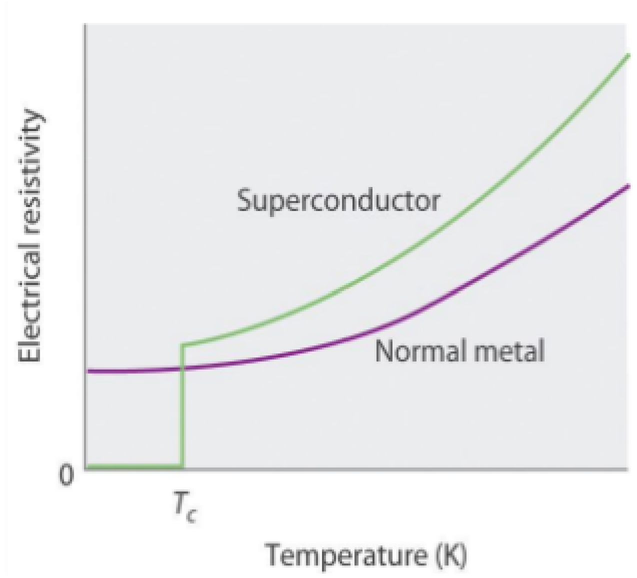

Figure 9 - Difference in behavior between a usual material and a superconducting material. **Source:** UFPR <http://fisica.ufpr.br/grad/supercondutividade.pdf>

The theory that answers this problem describes the following: Electrons that move freely through the material attract positive ions from its structure, resulting in a concentration of positive ions. The deformation in the region of concentration propagates as a vibration wave in the network, called Phonon. The Phonon attracts a second Electron, as there is a large concentration of Ions with positive charges, so this second Electron absorbs the **momentum** carried by the Wave. In Figure 10, the electron-phonon-electron interaction whose name is “Cooper's pair” is presented. When a material goes from superconducting to usual, or vice versa, it is noted that a symmetry break occurs with Mass Generation (BELUSSI; NATTI; NATTI; PIMENTA, 2013, p. 3).

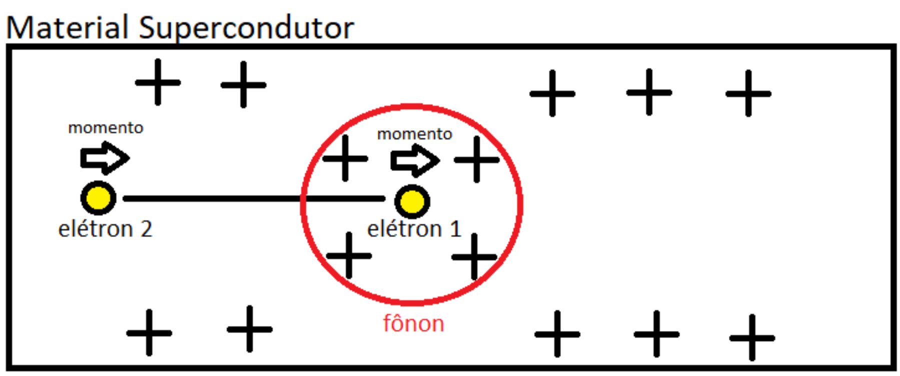

Figure 10 - Electron-Phonon-Electron interaction. **Source:** Author's image

> (..) When breaking the Cooper pair with increasing temperature, the pairing symmetry is also broken, and consequently there is a “generation” of mass in the quantity Δ. In other words, the mass of this system is modified as the symmetry created by the pairing of electrons, in the superconducting state, is undone (broken). Finally, note that it is the “emergence” of the phonon that generates the interaction between free electrons, that is, the phonon is the

> mediating particle of the BCS interaction. (BELUSSI; NATTI; NATTI; PIMENTA, 2013, p. 4)

3.5. Nuclear Pairing Theory in the Liquid Drop Model

An Atomic Nucleus is formed by Protons and Neutrons, and the Mass of an unbound system of Z Protons and (A - Z) Neutrons is the sum of the constituent Masses, ie:

$$M = Zmp + (AZ)mn \tag{20}$$

However, the Atomic Nucleus is a system linked by the Strong Nuclear Force, so, to separate the Hadrons, it is necessary to provide Energy to break this link. According to Restricted Relativity, the Mass of an Atomic Nucleus and the Mass of an unbound system obey the equation:

$$Mn(A,\ Z)c^2 + B(A,\ Z) = Zmn \cdot c^2 \tag{21}$$

Arranging this formula, we get:

$$B(A,\ Z) = [Zmp + (AZ)mn - Mn(A,\ Z)]c^2 \tag{22}$$

Atomic Nucleus is [B(A, Z)], therefore, being the Binding Energy of Hadrons, the number of Protons is (Z), the Mass of the Proton is (mp), the number of Neutrons is (AZ), the Mass of the Neutron is (mn), the number of Hadrons is (A), the Mass of the Atomic Nucleus is (Mn).

In this system, the greater the connection of a Nucleus, the smaller is the Mass of that same Nucleus. The binding of this system increases if the number of Protons and Neutrons are equal and if the number of Protons with "spin up" is equal to the number of Protons with spin "down", complying with the **Pauli Exclusion Principle**[15]. (BELUSSI; NATTI; NATTI; PIMENTA, 2013, p. 5).

> (..) Experimentally, nuclei with the number of protons Z and the number of neutrons N, both pairs, present a higher binding energy per nucleon (...) Analogously to the BCS mechanism, the increase in binding energy per nucleon , in the case of pair-pair nuclei, implies a decrease in the mass of these nuclei (...) the formation of a bound (paired) state of two nucleons, changed the mass of the nucleon-nucleon system. (BELUSSI; NATTI; NATTI; PIMENTA, 2013, p. 6)

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[15] O Princípio de Exclusão de Pauli diz que nenhum par de Partículas (exceto Bósons), podem estar no mesmo estado quântico. Por exemplo, um Elétron de spin "para cima" não pode estar em um mesmo sistema com outro Elétron de spin "para cima", apenas pode existir pares de Elétrons com spins opostos.

3.6. The Higgs Boson and the Higgs Field

The theory given by Peter Higgs (and other physicists individually) has been strongly supported by these Mass-Generating Symmetry Breaking theories and bears resemblance to the phenomenon of the Electron-Phonon-Etron system from BCS theory.

In the mid-1960s and 1970s, physicists mathematically described the interactions of Fundamental Interactions (except Gravitational Interaction) with Fermions and Bosons in a Symmetrical way. When trying to add Mass to Fermions, or even to Bosons, one can see the mathematical possibility of such addition, but this new formula becomes Asymmetric, since Gauge symmetry describes that all Particles must not have Mass. The challenge was how to add Mass to matter without the Symmetry being ruined, so a new term was created that would deliver Mass to Particles, the Higgs Boson. Thus, turning Mass into an acquired property of Particles. (GREENE, 2013).
The standard Model Lagrangian[16] is:

$$\mathcal{L} = 0 - \frac{1}{4}W_{\mu\nu}W^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G_{\mu\nu}G^{\mu\nu} + \tag{23.1}$$

$$+ \Psi_j\gamma^{\mu}\left(i\partial_{\mu} - gt_j \cdot W_{\mu} - g'Y_jB_{\mu} - g_s\mathbf{T}_j \cdot \mathbf{G}_{\mu}\right)\Psi_j + \tag{23.2}$$

$$+ \left|D_{\mu}\phi\right|^2 + \mu^2|\phi|^2 - \lambda|\phi|^4 - \tag{23.3}$$

$$- \left(y_j\Psi_{jL}\phi\Psi_{jR} + y'_j\Psi_{jL}\phi_c\Psi_{jR} + conjugate\right) \tag{23.4}$$

The first line of the Lagrangian explains the Kinetic Energy carried by Bosons W+, W-, Z, γ and g. The second line explains the interaction of Fermions with Vector Bosons, and the first term in the second line represents the Kinetic Energy of Massive Fermions. The last two lines contain the term of the Higgs Boson, so the third line describes Kinetic Energy, Mass and the self-interaction between the Higgs Bosons. Finally, the fourth line describes how the Higgs Bosons interact with the Fermions, generating Mass (BELUSSI; NATTI; NATTI; PIMENTA, 2013, p. 8).

The Higgs Field permeates the entire Universe and all Particles interact with it. Its differential is that when a Particle Interacts with the Field, it suffers a Resistance/Energy from it, for example, an Electron has a Mass of 0.511 MeV[17] (a magnitude of Energy/Mass), therefore the Energy that the Electron suffers from the Field of Higgs is 0.511 MeV.

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[16] Lagrangian links the Conservation of Mechanical Energy with the Conservation of a Linear Moment.
[17] MeV é Mega Elétron-Volts. Mega é prefixo e Elétron-Volts é quantidade de Energia Cinética ganha por um Elétron singular (ou qualquer partícula que tenha uma Carga Elementar), quando acelerado por uma diferença de Potencial Elétrico de 1 Volt, no vácuo. 1 eV é equivalente a 1,6 * 10 ^ -19 J.

Therefore, a particle that interacts with the Higgs Field suffers a certain Energy from this Field, the greater the Particle-Field interaction, the more the particle suffers Energy (LOOS, 2021).

> (..) So, when the Higgs field, which permeates the entire universe, receives enough energy, it creates a particle, the Higgs, which is an excitation of the Higgs field. On the other hand, when the Higgs particle interacts with other elementary particles (electrons, quarks,...), it transfers energy, in the form of mass, from the Higgs field to the elementary particle. Remember that mass is a form of energy. Therefore, depending on the strength of the Higgs interaction with an elementary particle, the Higgs field determines the "amount" of mass of this particle. Similarly, we know that an electron when interacting with a photon in the presence of an electromagnetic field gains (or loses) energy, in kinetic form. (BELUSSI; NATTI; NATTI; and PIMENTA, 2013, p. 2)

The Bosons of the 4 Fundamental Interactions are called vectors, since, for example, to generate a Force, 2 or more bodies are needed, therefore, a vector action, however, a Field is the action of an Interaction in itself, therefore, not vector. There is no Higgs Boson exchange between Particles as there is no Higgs Force, however, there is a Higgs Field, so when a Particle interacts with the Higgs Field, it releases and absorbs Higgs Bosons, as, every Particle that interacts with a given Field, it emits and absorbs respective Bosons of that Field Interaction.

However, it is not possible to detect a Field, but it is possible to detect its Boson that validates the existence of the respective Field, in this way, the "Boson Hunt" was started, however, the Higgs Boson interacts strongly with its Field, in other words, detecting it would not be an easy task as it requires highly advanced technologies of High Energy generators. (MOREIRA, 2011, p. 108).

Understanding the Higgs mechanism is quite complex and, even for some physicists, such an idea is difficult to absorb. In 1993, the British Science Minister challenged physicists to explain this theory as simply as possible. By referring to a bottle of high-quality champagne, the winning explanation went something like this:

> Suppose there is a huge cocktail party in the CERN lab, full of particles from physics researchers. This multitude of physicists represents the Higgs field. If a tax collector walked into the cocktail party, no one would want to talk to him, and he could easily walk across the room to reach the bar. The tax collector would not interact with the crowd the way some particles do not interact with the Higgs field... Suppose Peter Higgs walked into the same room, perhaps wanting a beer. In this case, physicists would immediately gather around Higgs to discuss with him his efforts to measure the properties of his boson. By interacting strongly with the crowd, Higgs would slowly move to the other side of the room. Continuing our analogy, Higgs became a huge particle throughout its interactions with the field (...) all particles are equal until they enter the room. Peter Higgs and the tax collector have zero mass, it's the interaction with the crowd that makes them mass. (Adapted. LINCOLN, 2013).

4. THE GREAT PARTICLE COLLIDER

A Particle Accelerator, from the collision Energy, makes Virtual Particles become real and depending on the Masses of the colliding particles, the Energy varies directly proportionally, that is, the more Massive the Particles that collide, more Energy is released. So, as the Higgs Boson interacts strongly with the Higgs Field, it is quite Massive, so it needs an extremely energetic collision to produce it. To generate such energy, CERN created the LHC, the largest Particle Collider in the world,

4.1. The history of the LHC

On September 29, 1954, CERN was created (in French: Conseil Européen pour la Recherche Nucléaire; in English: European Council for Nuclear Research), a laboratory with the aim of studying Atomic Nuclei and also to stop relying on the United States and the Soviet Union for scientific research on Particles.

In 1959, the first Particle Accelerator was created by CERN, the Proton Synchrotron, and CERN changed its name to another (in French: Organization Européenne pour la Physique de Particles; in English: European Particle Physics Organization), therefore, the focus of the laboratory's scientific studies became broader for all Particles. In 1972, the Proton Synchrotron Booster, the smallest of all Accelerators today, was inaugurated, with the aim of supporting the Proton Synchrotron. In 1976, laboratory scientists and engineers made the Super Proton Synchrotron, a more powerful Particle Collider than previous ones. On October 11, 1989, CERN introduced the newest, most powerful and largest Particle Accelerator of the time, the LEP (Large Electron-Positron Collider).

The LEP, as it collided with “light” Particles, its performance parameters were unexpectedly low, as it was the biggest Accelerator in the world at the time, so in 1994 CERN's board approved the construction of a new Particle Accelerator that would literally take the place of the LEP, the LHC (Large Hadrons Collider).

The LHC has its shutdown phases and it is currently out of operation (Figure 11), as it takes approximately 120 MWto accelerate these Particles[18] (Megawatts), so the LHC is turned off for a period of time. (CERN, 2010)

[18] This electrical consumption is almost equivalent to twice the power of the Rolls Royce 900 engine in an Airbus A380s aircraft on a flight at around 850 km/h

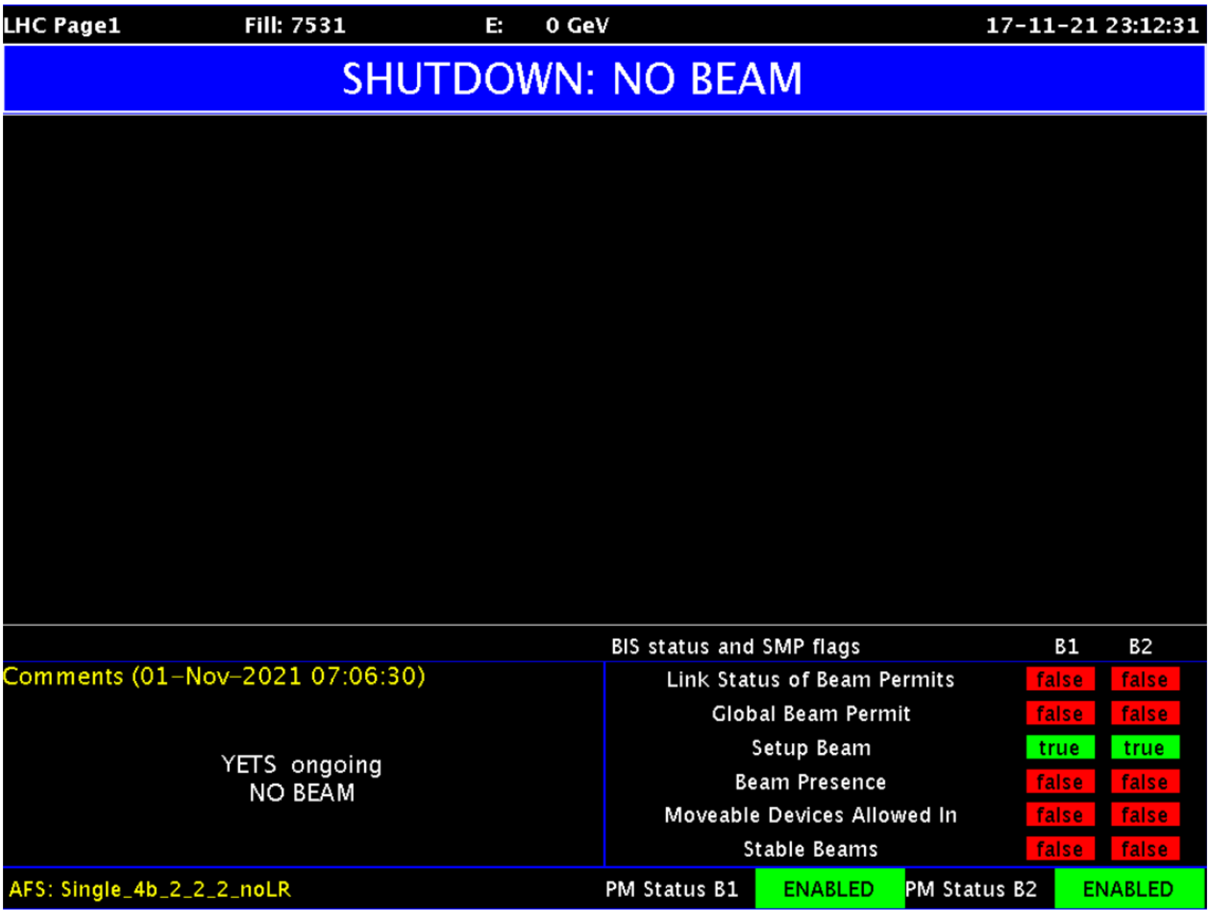

Figure 11 - LHC out of operation. **Source:** The Large Hadron Collider | CERN.

4.2. Engineering Plan

The LHC is the largest collider in the CERN Accelerator Complex, measuring 26,659 meters in circumference. The other main colliders are Linac 2 (37 meters) - which is a Linear Collider, Proton Synchrotron Booster (25 meters), Proton Synchrotron (628 meters) and Super Proton Synchrotron (approximately 7,000 meters). Figure 12.

The Large Collider is separated into 8 octants, the most important being the 1, 2, 5 and 8 in which the ATLAS, ALICE, CMS and LHCb detectors are, respectively, at the points of intersection of the tubes, where collisions occur (CERN, 1995, p. 6). Figure 13.

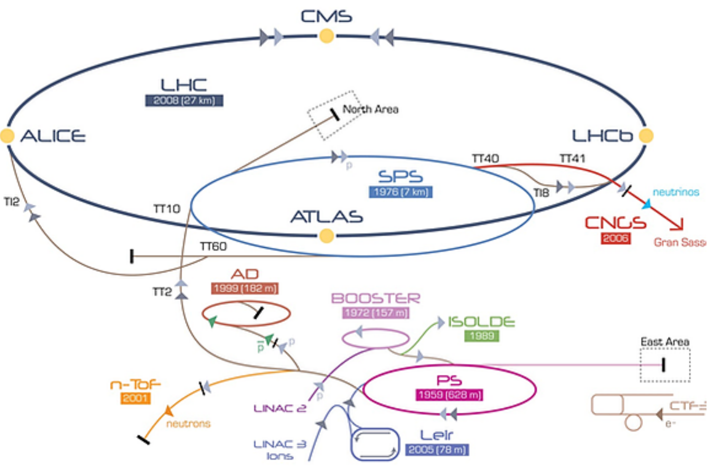

Figure 12 - CERN Particle Accelerator Complex. **Source:** Wikipedia

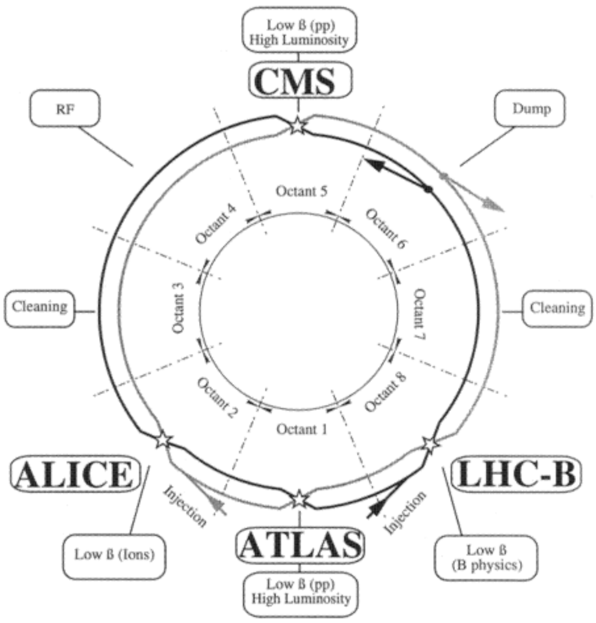

Figure 13 - LHC Schematic Layout. **Source:** THE LARGE HADRON COLLIDER: Conceptual Design.

The Particle Accelerator tubes contain magnets in type II superconductivity[19]; dipole magnets (with two poles) of 15cm each, to bend the beam around the LHC and quadripolar magnets (with 4 poles) to focus the beams. Superconducting magnets potentiate the Magnetic Field more than traditional magnets so that it amplify the Potential Magnetic Energy. In order for these magnets to be in a superconducting state, they are cooled to -271.3°C (1.85K) by a Helium Superfluid cryogenic system[20]. Furthermore, so that the accelerated particles do not

[19] There are 2 types of Superconductivity, type I causes the Magnetic Field not to pass through the material due to something called the Meissner Effect, however, unlike type II, which is still in a state of zero resistance, however, with the Field Magnetic passing through the material in a vortex.

[20] Atoms do not follow the Pauli Exclusion Principle, therefore, Helium Superfluid has its molecules condensed, functioning as just one large molecule. This makes it have no viscosity, which can be observed experimentally by leaking Helium Superfluid from a container.

suffer friction, these tubes contain an Ultra High Vacuum process, which in the case ofColliders Particle, causes the pressure inside the tubes to be below at least 10^{-5} Pascals (SIMONS , 2018). Figure 14.

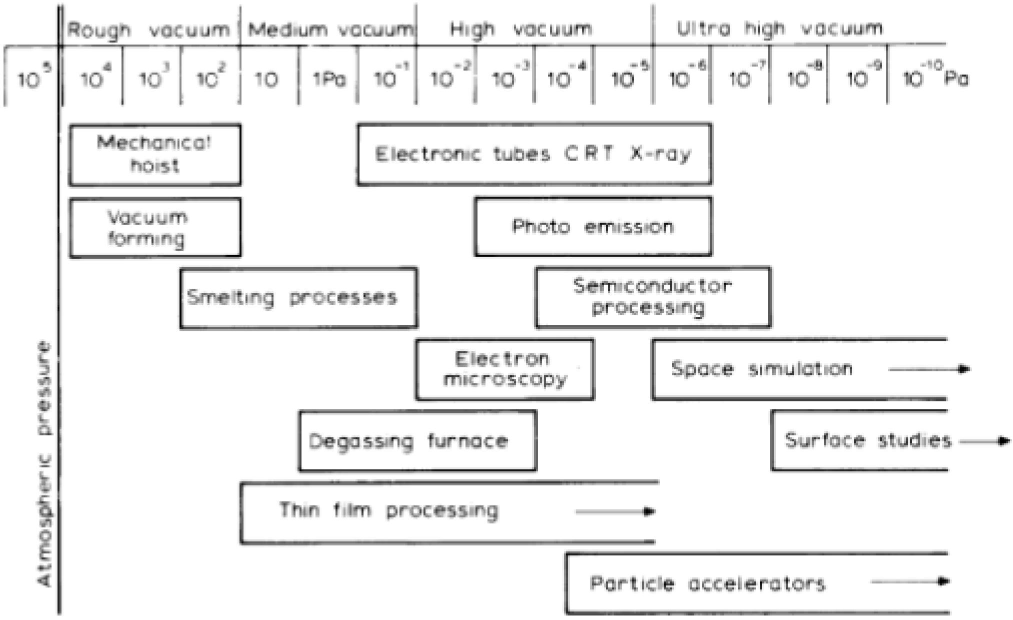

Figure 14 - Vacuum Scale and Applications. **Source:** Ultrahigh Vacuum Practice.

4.3. How the Collider Works

The LHC works as follows: A bottle containing gaseous hydrogen is induced by Electromagnetic Waves which make the Atomic Nuclei eject to a Linear Accelerator, the Linac 4, which linearly accelerates the Hadrons until reaching 150 Mega Electron-Volts (Me v). After that, Linac 4 transfers the Beams to the PS Booster Accelerator, which accelerates them centripetal to 91.6% of the speed of light in a vacuum, with 1.4 GeV. The PS Booster releases the Beams to the PS (Proton Synchrotron), which accelerates the 99.93% of the speed of light, with 25 GeV. The PS emits the Hadrons for the penultimate stage, the SPS (Super Proton Synchrotron), which accelerates them up to 99.9998% of the speed of light, with 450 GeV. And finally the LHC, which accelerates the $2.4 \cdot 10^{13}$ particles to 99.9999991% of the speed of light, with 7 TeV. At the LHC the Protons are on a collision course, repeating 12 laps in 16.8 seconds, with a run of just 20 minutes in duration. Furthermore, the Energy obtained from collisions between Hadrons is approximately 13 TeV (LHC Conceptual Design, 1995, p. 7). In Figure 15, the performance tables are shown.

Energy	[TeV]	7.0
Dipole field	[T]	8.4
Coil aperture	[mm]	56
Distance between apertures	[mm]	194
Luminosity	[cm^{-2} s^{-1}]	10^{34}
Beam–beam parameter		0.0034
Injection energy	[GeV]	450
Circulating current/beam	[A]	0.54
Bunch spacing	[ns]	25
Particles per bunch		10^{11}
Stored beam energy	[MJ]	334
Normalized transverse emittance	[μm.rad]	3.75
r.m.s. bunch length	[m]	0.075
β-values at I.P. in collision	[m]	0.5
Full crossing angle	[μrad]	200
Beam lifetime	[h]	22
Luminosity lifetime	[h]	10
Energy loss per turn	[keV]	6.7
Critical photon energy	[eV]	44.1
Total radiated power per beam	[kW]	3.6

Quantity	Number
Circumference	26659 m
Dipole operating temperature	1.9 K (-271.3°C)
Number of magnets	9593
Number of main dipoles	1232
Number of main quadrupoles	392
Number of RF cavities	8 per beam
Nominal energy, protons	6.5 TeV
Nominal energy, ions	2.56 TeV/u (energy per nucleon)
Nominal energy, protons collisions	13 TeV
No. of bunches per proton beam	2808
No. of protons per bunch (at start)	1.2 x 10^{11}
Number of turns per second	11245
Number of collisions per second	1 billion

Figure 15 - LHC Performance Parameter (1995). **Source:** THE LARGE HADRON COLLIDER: Conceptual Design.

In the collision between Hadrons, any Particles in the Particle Zoo can emerge from them, because the Energy of the collision makes that Virtual Particles in that space, have enough Energy to become real. However, it is not just any particle that appears, as it depends on the Energy generated by the collision, therefore, “heavier” Particles need more Energy to be generated.

> (..) in an electron and positron (real) annihilation experiment in a particle accelerator/collider, real muons appear that are observed in particle detectors (...) a virtual muon-antimuon pair received resulting energy of annihilation and left the (very small) region where the interaction took place. (MOREIRA, 2011, p. 104).

The Energy required to create particles in a Particle Collider is due to the Center of Mass Energy, which is the measure of the Energy available for new Particles to appear (MARTIN; SHAW, 2008, p. 76). It is given by the equation:

$$Ecm = \sqrt{m_b^2 + m_t^2 c^2 + 2m_t c^2 El} \tag{24}$$

As the Accelerator magnets are type II superconductors, the Magnetic Field that passes through the material is in a vortex, by account of the rotation of electrical charges through the material. And if we treat the rotation of these charges as a Spiral, the Magnetic Field of a magnet is amplified by the Magnetic Field of that rotation of charges. This is the reason why superconducting magnets have a stronger Magnetic Field than traditional magnets (CAPAZ, 2019). Figure 16 shows a type II superconductor.

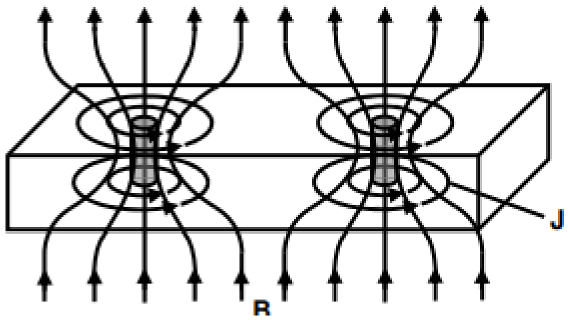

Figure 16 - Schematic diagram showing a magnetic flux penetrating a superconductor via flux vortices. **Source:** Imaging Flux Vortices in Type II Superconductors with a Commercial Transmission Electron Microscope.

Particle Colliders can also be interpreted as a kind of Spiral[21], due to the rotational movement of the Protons as an electrical charge, so certain laws and principles can be attributed to the Accelerators. If we apply the Biot-Savart Law[22] to determine the Torque[23] exerted on a rectangular PQRS Spiral (Figure 17), under the influence of a Magnetic Field (FILHO, *sd*, p. 15), we have that:

1. The Spiral area is $A = ab$.
2. There is a current I passing through the loop, the Magnetic Field is normal to the X axis, making an anglethe loop θ with the normal toplane.
3. Applying the equation $dF = I(dl \cdot B)$ of the Biot-Savart law, the force Fx acting on the PQ side $(x = IbB \cdot cos\theta)$, being opposite Force Fx acting on the RS side $(x = IaB \cdot cos\theta)$. Figure 17.1
4. The perpendicular distance between the lines of action of force F in each segment of the loop is $\Delta S \cdot sin\theta$. Figure 17.2

Therefore, the Torque that the Spiral experiences is:

$$\tau = (IA) \cdot B \cdot sin\theta \quad (25)$$

$$\tau = m \cdot B \quad (26)$$

(τ) is the Torque. (A) is the Spiral area. (I) is the electric current. (dF) is the Force at a given point. (dl) is some point of the Spiral. (B) is the Magnetic Field. (m) is the Moment of the Magnetic Dipole.

[21] Spiral is an electrical current in a closed circuit that generates a Magnetic Field due to the rotation of Particles with electrical charge.
[22] Biot-Savart's Law is an equation that supplies a Spiral's Magnetic Field.
[23] Torque is the moment of rotation of a body after applying a Force to it.

With this, we can deduce that the Magnetic Potential Energy of a Moment of the Magnetic Dipole, in a Magnetic Field is:

$$Emag. =- m \cdot B \cdot cos\theta \tag{27}$$

And as Energy has the property of transformation according to the Law of Conservation of Energy. In an Accelerator, the Magnetic Potential Energy is transformed into Kinetic Energy for the Particles collision, so, therefore, having a powerful Magnetic Field directly influences the amount of Energy generated from these collisions.

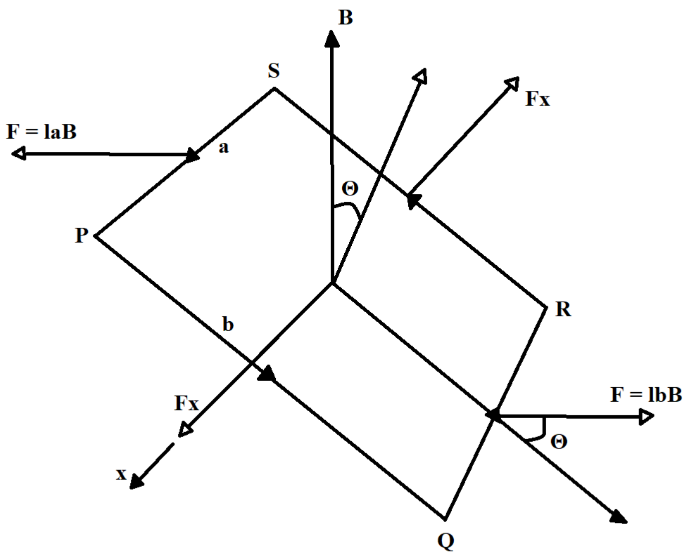

Figure 17.1 - Rectangular loop passing a current *I* in a uniform magnetic field. **Source:** Copyright Image.

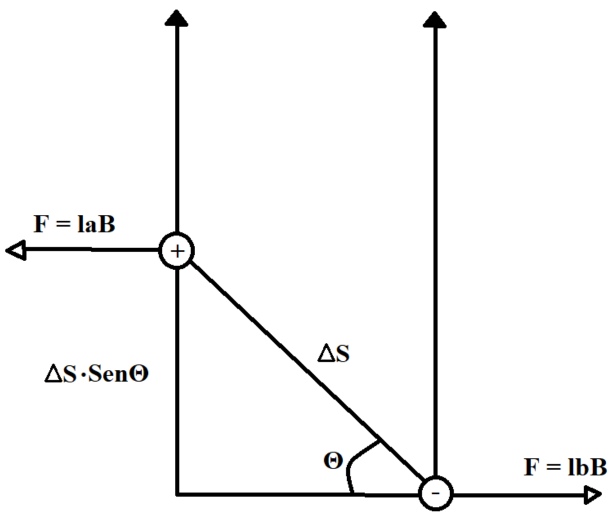

Figure 17.2 - Torque exerted on the Spiral. **Source:** Copyright Image.

4.4. Discovery of the Higgs Boson

One of the 4 LHC detectors is the ATLAS (General-Purpose pp Experiment at the Large Hadron Collider at CERN) and the CMS (Compact Muon Solenoid), they were one of the first detectors created by CERN . ATLAS and CMS were created with the main objective of exploring the origin of Mass and Electroweak Theory and its Symmetry Breaking, therefore, with the objective of detecting the Higgs boson. The objectives of these detectors are not exclusive to the Higgs boson, they also act in other areas, for example, in the decay of Top Quarks.

The Higgs boson has a very fast decay, so the difficulty was also linked to identifying the Higgs boson from Particles generated by decay, which can be (CERN, 1992, p. 1):

$$H \rightarrow \gamma\gamma \text{ by the decay of } WH,\ ZH \text{ or } t\bar{t}H \text{ using a tag of } l\pm,\ 80 \text{ Gev} < mH < 130 \text{ GeV} \quad (28.1)$$

$$H \rightarrow \gamma\gamma \text{ in a direct decay, } 90 \text{ GeV} < mH < 150 \text{ GeV} \quad (28.2)$$

$$H \rightarrow ZZ^* \rightarrow 4l\pm,\ 130 \text{ GeV} < mH < 2mZ \quad (28.3)$$

$$H \rightarrow ZZ \rightarrow 4l\pm \text{ or } 2l\pm\ 2\nu,\ 2mZ < mH < 800 \text{ GeV} \quad (28.4)$$

$$H \rightarrow WW \text{ or } ZZ \rightarrow l\pm\ \nu \text{ 2 jets or } 2l\pm \text{ 2 jets or } 2l\pm\ 2\nu \text{ or } 4l\pm \text{ by fusion of } WW \text{ or } ZZ \text{ using advanced jet marking for } mH \text{ up to 1 TeV} \quad (28.5)$$

The Higgs boson is (H), the Photon is (γ), the Boson W is (W), Boson Z is (Z), Quark Tau is (t), Antiquark Tau is ($\bar{t}$), Leptons Muons and Electrons and their Antiparticle derivatives are (l±), the Boson Mass of Higgs is (mH), the broken Z boson[24] is (Z*), the Mass of a Hadron is (mZ) and the jets are energetic jets.

On July 4, 2012, there was the largest Particle Physics conference of that year in Melbourne, a city in Australia. The ATLAS and CMS detectors, responsible for researching the origin of the Mass and the Symmetry Breaking of Electroweak Theory, had detected a

[24] A broken Boson is one that breaks the CPT Symmetry.

new Particle with a Mass close to 125 GeV, which was possibly the Higgs Boson, and having a decay or (28.1) or (28.2). Figures 18 show the detection of the Higgs boson by ATLAS and CMS.

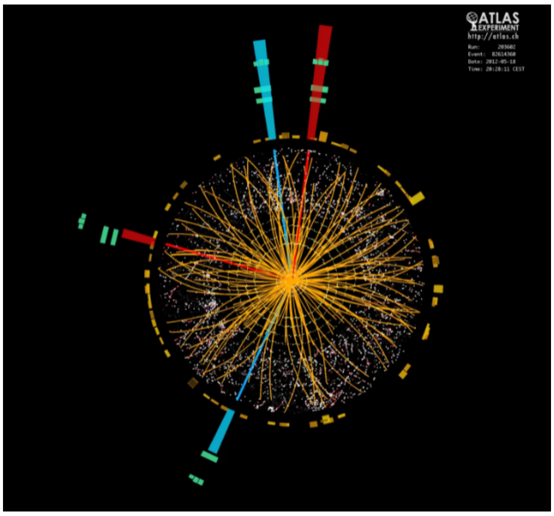

Figure 18.1 - Detection of the Higgs Boson by ATLAS. **Source:** Revista Galileu

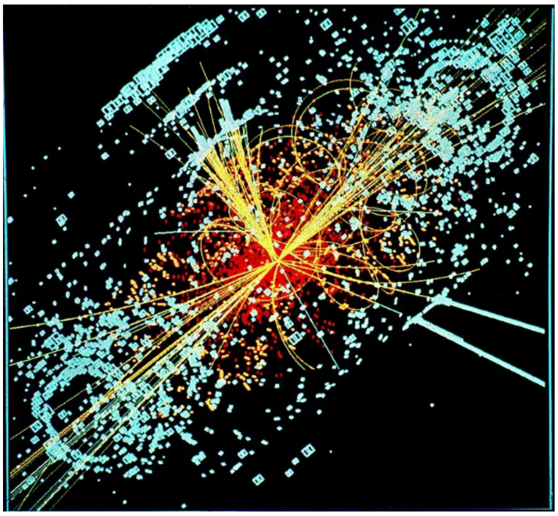

Figure 18.2 - Detection of the Higgs Boson by CMS. **Source:** Revista Galileo

5. FINAL CONSIDERATIONS

Because man has an “Arché” ideology, the Science of Particle Physics managed to emerge, discovering new extremely small structures, laws and rules that are totally different from Classical/Traditional Physics and hitherto unknown properties. Some of these properties are still being studied and one property that came to be studied nearly 100 years ago was Mass, more specifically the Intrinsic Mass of Fundamental Particles.

The desire scientists had to study Mass more deeply was due to the problem of the Electroweak Theory of Weak Interaction Mediating Particles having Mass, which is totally contradictory to Gauge Theory, one of the most renowned theories of Particle Physics.

Thus, after many studies and pioneering sciences, a mechanism of Mass Generation was theorized around 1960, by Peter Higgs and other individual scientists such as François Englert, who played a large part in the theory. The way this Mass Generation was formulated is that there is a non-vector Higgs Boson, therefore mediator of its respective non-vector Interaction, the Higgs Field.

Unlike other fields, a Particle that interacts with the Higgs Field suffers an Energy and such Energy is equivalent to the Mass of that particle, that is, the Mass of a particle is nothing more than the Energy that the Particle suffers from the Higgs Field. As every interaction of a Particle in a Quantum Field causes it to emit and absorb Bosons of the respective Field, the Particle that interacts with the Higgs Field emits and absorbs Higgs Bosons.

There is no way to detect a Quantum Field, but it is possible to detect its Boson, thus discovering the Field. Therefore, to detect the Higgs Boson, it was necessary a Particle Accelerator 27km in circumference, which through the thunderous Energy of this collision, causes Virtual Particles, including the Higgs Boson, to appear and be detected.

The discovery of the Higgs Boson is stimulating for Science, as this is the first big step towards the unification of Interactions. Fundamental. The Higgs Boson of the truth Electroweak Theory, our first unification so far, furthermore, the Higgs Boson explains the Mass of the other Particles Standard Model. The topic addressed in this TCC is current, the Higgs Boson was discovered just 8 years ago this article was delivered. For me it is encouraging that a new era of Particle Physics has started and I, as a dreamer, want to be one of the forerunners of this new Science.

The LHC is at all times beating its own record in Energy exerted in Particle Collision, improving technologically and I believe that it will not take long for Electroweak and Strong Nuclear unification, which would be the second big step for the Theory of Everything . O último passo seria trazer a Gravidade no escopo quântico, na chamada Gravitação Quântica e somente após isso a unificação das 4 grandes interações que regem as regras do Universo aconteceria.

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