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Analysis of the Higgs boson through CIMA MasterClass: an educational experience with Modern Physics students at the Central University of Ecuador

Análisis del Bosón de Higgs mediante MasterClass CIMA: una experiencia educativa con estudiantes de Física Moderna de la Universidad Central del Ecuador

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Abstract

Higgs and other physicists as part of the Standard Model of particle physics. Its existence explains the mechanism by which elementary particles acquire mass, postulating the presence of an invisible field, the Higgs field, that permeates the entire universe. When particles interact with this field, they obtain mass proportional to the intensity of their interaction. For

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decades, scientists searched for experimental evidence of this particle. Finally, in 2012, experiments conducted at the Large Hadron Collider (LHC) at CERN confirmed its existence, validating the Standard Model and marking a milestone in modern physics. Due to its importance in understanding the universe, the Higgs boson was nicknamed the "God particle," although this term generated some controversy within the scientific community. Its discovery allowed scientists to delve deeper into the origin of matter's fundamental properties and explore new frontiers in physics, such as its relationship with dark energy and the fate of the universe. This study aims to demonstrate collaborative work and the identification of elementary particles using the CIMA simulator, available at www.i2u2.org/elab/cms/, with the collaboration of students from the Physics and Mathematics program at the Central University of Ecuador during the 2024-2025 academic period, enabling an interactive exploration of particle physics.

Keywords: Higgs boson, Standard Model, Energía Oscura, Dark Energy, Campo de Higgs, Higgs Field.

Resumen

El bosón de Higgs es una partícula fundamental propuesta teóricamente en 1964 por Peter Higgs y otros físicos como parte del Modelo Estándar de la física de partículas. Su existencia explica el mecanismo por el cual las partículas elementales adquieren masa, postulando la presencia de un campo invisible, el campo de Higgs, que permea todo el universo. Cuando las partículas interactúan con este campo, obtienen una masa proporcional a la intensidad de su interacción. Durante décadas, los científicos buscaron evidencia experimental de esta partícula. Finalmente, en 2012, los experimentos realizados en el Gran Colisionador de Hadrones (LHC) del CERN confirmaron su existencia, validando el Modelo Estándar y marcando un hito en la física moderna. Debido a su importancia en la comprensión del universo, el bosón de Higgs fue apodado "la partícula de Dios", aunque este término generó cierta controversia en la comunidad científica. Su descubrimiento permitió profundizar en el origen de las propiedades fundamentales de la materia y explorar nuevas fronteras en la física, como su relación con la energía oscura y el destino del universo. Este estudio tiene como objetivo evidenciar el valor del trabajo colaborativo y la identificación de partículas elementales mediante el uso del simulador CIMA, promoviendo una aproximación interactiva y formativa a la física de partículas en estudiantes universitarios. El paradigma que subyace en la búsqueda del bosón de Higgs, disponible en www.i2u2.org/elab/cms/,con la colaboración de los estudiantes de la carrera de Física y Matemática de la Universidad Central del Ecuador durante el período 2024-2025, permitiendo explorar la física de partículas de manera interactiva

Palabras clave Bosón de Higgs, Modelo Estándar, Energía Oscura, Campo de Higgs

Introduction

Advances in modern physics have been driven by the integration of innovative technology with teaching methods that foster the connection between theory and practice. In this context, Masterclass's CIMA simulator has established itself as an essential tool for exploring elementary particles, enabling real-time measurement and analysis of events related to the Higgs boson.

In the search for the Higgs boson, students not only acquire theoretical knowledge about the interaction of fundamental particles, but also apply concepts in simulated experimental environments, reinforce their understanding through direct observation of physical processes. This experience facilitates active learning, where participation and analysis are essential for the construction of knowledge.

In addition, the approach used in CIMA's Masterclass highlights the interconnection between the Higgs boson and particles such as quarks (especially the top quark) and gauge bosons, offering a detailed view of how the Higgs boson confers mass on other fundamental particles. The ability to visualize and study these phenomena within a simulated environment transforms teaching into a meaningful process, in which theory comes to life through experimentation and critical analysis.

This initiative is carried out by the teachers and students of the ninth semester of the Optics and Modern Physics course, belonging to the Experimental Sciences, Mathematics, and Physics Education program at the Central University of Ecuador. Through the use of advanced technology such as the CIMA simulator, participants strengthen their understanding of particle physics, promoting deep and applied learning, which is essential in 21st-century scientific education.

In summary, these research activities promote participatory, contextualized, and research-oriented higher education, where students become protagonists in the process

Methodology

The methodological approach of this research is based on a constructivist and scientific inquiry paradigm, in which students actively participate in the construction of knowledge through the analysis of simulated data and its comparison with the Standard Model.

By involving students in real simulations of particle collisions, experiential learning is promoted that goes beyond abstract theory. The search for the Higgs boson integrates knowledge of physics, mathematics, statistics, computing, and the philosophy of science, which enriches the student's comprehensive education. Analyzing experimental data, interpreting results, and contrasting them with theoretical predictions strengthens key skills in scientific training.

Studying a discovery as recent and revolutionary as that of the Higgs boson awakens interest in research and shows that modern physics is alive and evolving. The use of tools such as CERN simulators or CIMA Masterclasses brings cutting-edge research closer to the university classroom.

The formation of student participants in the CIMA Masterclasses platform, whose objective was to carry out an experimental simulation aimed at searching for the Higgs boson, based on the principles of the Standard Model of particle physics.

During the activity, a specialized simulator was used that replicates high-energy proton collisions, similar to those that occur in the Large Hadron Collider (LHC). In total, 100 simulated proton-proton collision events were analyzed, seeking to identify signals compatible with the decay of the Higgs boson.

Since the Higgs boson is highly unstable and decays almost instantaneously, its direct detection is not possible. Instead, the particles generated after its decay are analyzed, identifying characteristic patterns—such as invariant mass—that match the theoretical predictions of the Standard Model. To increase the reliability of the results, it was necessary to repeat the experiment multiple times and perform statistical analyses on the collected observations.

Results

ATLAS (A Apparatus for the Investigation of Lepton and Hadron Scattering) is a particle detector located at the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland. It is one of the two largest detectors at the LHC, along with CMS.

ATLAS is made up of 3,000 scientists from 180 institutions around the world, representing 38 countries from every inhabited continent. It is one of the largest collaborative efforts ever undertaken. Nearly 1,200 doctoral students are involved in detector development, data acquisition, and analysis. The collaboration depends on the efforts of countless engineers, technicians, and administrative staff. ATLAS is the largest detector ever built for a particle collider. It is 46 meters long and 25 meters in diameter, and is located in a cavern nearly 100 meters underground.

The detector consists of six different subsystems located in concentric layers around the collision point to measure the trajectory, momentum, and energy of the particles, allowing them to be identified and measured individually. A gigantic system of magnets curves the trajectory of the charged particles so that their momentum can be measured as accurately as possible.

Beams of particles traveling in the LHC at energies of up to 7 trillion electron volts, or speeds of up to 99.9999991% that of light, collide in the center of the ATLAS detector, producing new particles that are emitted in all directions from the collision point. Every second, more than a billion interactions occur in ATLAS, which is equivalent to all the people on Earth having 20 telephone conversations simultaneously. Of these collisions, only one in a million is selected as potentially interesting for recording and further study.

The detector records and identifies particles to investigate a wide variety of physical processes, from the study of the Higgs boson and the top quark to the search for extra dimensions and particles that may constitute dark matter. ATLAS explores a wide variety of physics topics, with the main goal of improving our understanding of the elementary constituents of matter. Some of the key questions ATLAS seeks to answer are:

Structure of the ATLAS Detector

The four main components of the ATLAS detector are:

1. Internal Detector: measures the momentum of each charged particle.

2. Calorimeter: measures the energy of neutral and charged particles.

3. Muon Spectrometer: identifies and measures the momentum of muons.

4. Magnet System: curves the trajectories of each charged particle, allowing their momentum to be measured.

Integrated with the detector components are:

· Event Selection (Trigger) and Data Acquisition System: a specialized multi-level computing system that selects physics events with specific characteristics.

· Computing System: develops and improves the software used to store, process, and analyze the immense amount of data in 100 computing centers located around the world.

Figure 1. ATLAS structure. Source: European Organization for Nuclear Research

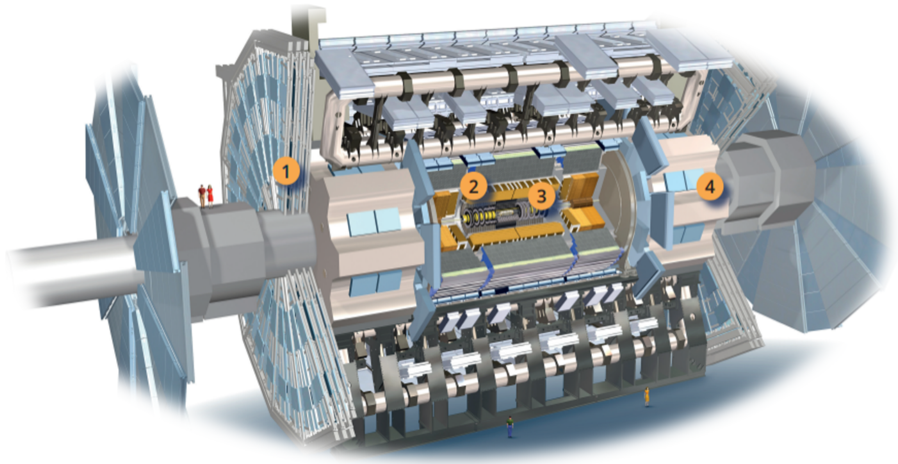
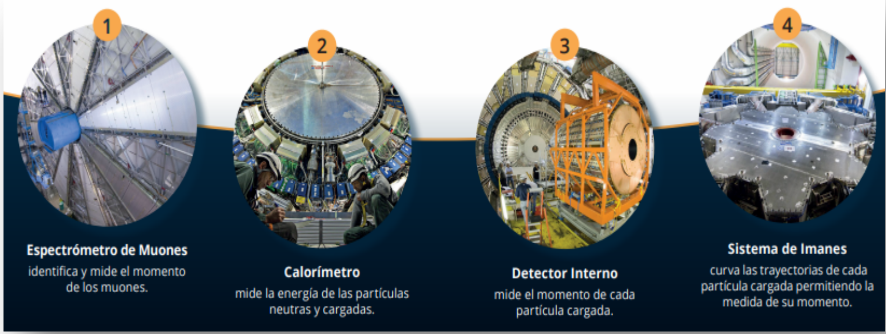


Figure 2. Detector components. Source: European Organization for Nuclear Research (CERN), 2019.



Applications in everyday life

The search for answers to fundamental questions about the properties of matter and forces requires cutting-edge technological developments, which often lead to important innovations. Some examples of how ATLAS's knowledge and technological innovation have been applied in everyday life are:

Energy storage with superconducting magnets

ATLAS's knowledge in the manufacture of superconducting magnets may open up the possibility of developing new high-performance energy storage systems.

Hadron therapy

The diamond sensors developed for future upgrades to ATLAS are also used to monitor hadron beams used in therapy, which are more efficient at destroying tumors than X-rays or electron beams, with less impact on nearby healthy tissue.

Medical imaging

Three-dimensional silicon sensors developed for future upgrades to ATLAS enable higher-resolution X-ray imaging. Most medical imaging techniques require the detection of photons in different energy ranges.

Retina project

Based on the technology used in ATLAS silicon microstrip detectors, a large-scale recording system for neuronal activity has been developed. These experiments are capable of understanding how living neural systems process and encode information, which could in the future provide artificial vision to blind people.

Augmented reality

ATLAS is researching innovative pattern recognition technologies, a key component of augmented reality applications, which allow workers involved in delicate maintenance operations to virtually visualize work procedures, minimizing intervention time and the risk of errors. This technology has various industrial applications.

Sound reproduction

The high-precision optical image processing methods used to measure and align each of the 16,000 silicon detectors in the ATLAS internal detector can be used to measure with great precision the grooves of mechanical sound carriers, such as vinyl records or phonograph cylinders. This technology is being developed for use in sound recording collections and archives to restore and preserve samples of great historical value.

Standard Model

The Standard Model of Particles is a fundamental theory of physics that describes the elementary particles that make up matter and the fundamental forces that govern them. It is a quantum field theory that has been experimentally confirmed with great precision and has revolutionized our understanding of the universe at the subatomic level. The Standard Model divides elementary particles into two large groups: fermions, which are the particles that constitute matter, and bosons, which are the particles that transmit forces. In addition, the model describes three of the four known fundamental forces: the electromagnetic force, the strong nuclear force, and the weak nuclear force. One of the key pieces of the Standard Model is the Higgs mechanism, which explains the origin of the mass of elementary particles. This mechanism postulates the existence of a Higgs field that permeates all space and interacts with particles, giving them mass. The Higgs boson is the elementary particle associated with the Higgs field and was first detected at the Large Hadron Collider (LHC) in 2012, confirming the validity of the Higgs mechanism and completing the Standard Model.

Structure

The Standard Model consists of 17 types of fundamental particles, which are distributed as follows:

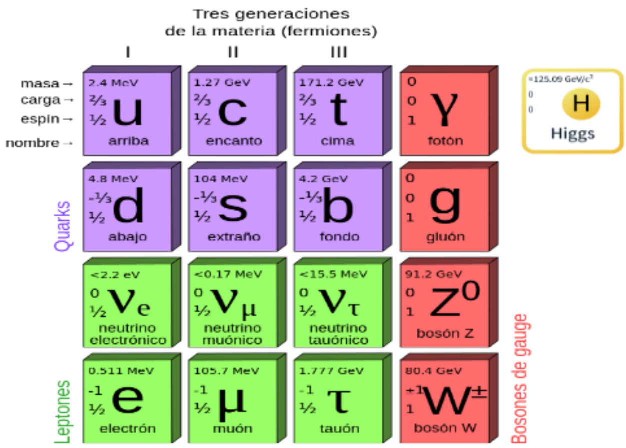
· Quarks: These are considered subatomic particles that make up nuclear matter and hadrons. They have a fractional electric charge and can be combined to form other particles. There are six types of quarks.

· Leptons: Their conformation is due to the basic components of matter. They are classified into three generations, each with a charged lepton and a neutrino. Charged leptons refer to electrons, muons, and tau, while neutrinos are neutral, and both can generate various combinations. Like quarks, there are six types of leptons.

· Bosons: These are subatomic particles that are responsible for transporting energy and forces, such as electroweak, gravitational, and strong interactions. They also play a fundamental role in the functioning of the universe. There are four types of bosons.

An essential fact about these particles is that each one has an antiparticle, which when they interact with each other, they destroy each other and generate other particles. To better understand this classification, we will refer to the following illustration.

Figure 3. Classification of particles. Source: Spanish Nuclear Society



Elementary Particles

These are the smallest components of matter and are therefore believed to be indivisible, as they are not made up of smaller structures and have no internal composition.

Throughout the history of physics, different models have considered different particles to be elementary. The atomic model held that the atom was the smallest unit of matter, while the nuclear model postulated that the components of the atom were indivisible. Currently, the standard model is the theoretical framework used to describe these particles.

Elementary particles are classified into two large groups:

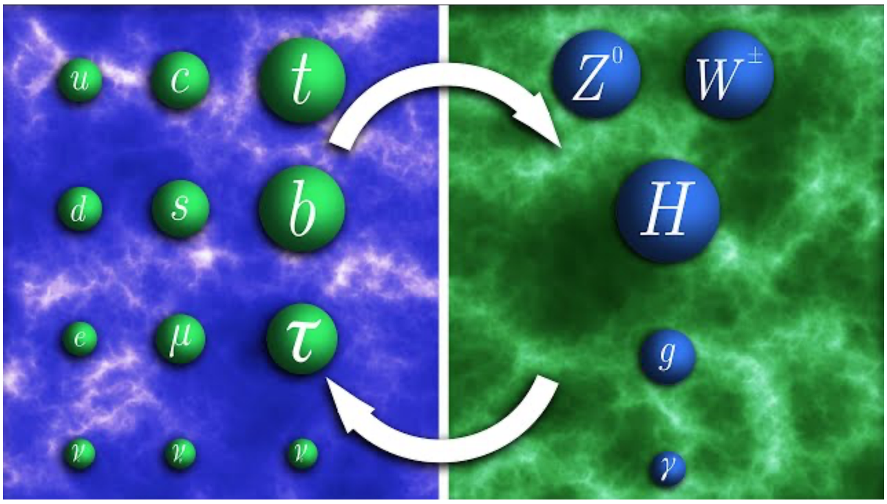


Figure 4. Classification of particles Source: Student Congress of Physics and Mathematics

· Fermions: These are the particles that constitute matter and obey the Pauli exclusion principle. They are divided into quarks (which form protons and neutrons) and leptons (such as electrons and neutrinos).

· Bosons: These are the particles responsible for transmitting the fundamental interactions of nature. Among them are the photon (electromagnetic force), the W and Z bosons (weak force), the gluon (strong force), and the Higgs boson, which gives mass to other particles.

On the other hand, hadrons are particles composed of other more fundamental particles, as they are made up of quarks, antiquarks, and gluons. They are classified into two types:

ü Baryons: These are made up of three quarks, along with some gluons and antiquarks. Most of them are unstable, with the exception of nucleons, i.e., protons and neutrons. In addition, baryons belong to the fermion group.

ü Mesons: These are composed of a quark, an antiquark, and a gluon. Although they are all unstable, they can exist in isolation. Mesons are also part of the bosons.

It should be noted that there are other particles that are important to address, such as:

o Hypothetical particles: These have been proposed theoretically, but their existence has not yet been confirmed experimentally.

o Superpartner particles: Suggested by supersymmetry theory, these would be the symmetrical counterparts of known particles.

o Quasiparticles: These are specific entities identified in the study of condensed matter.

Magnetic field of particles

This is a property that arises from their moving electric charge and their intrinsic magnetic moment, which is related to their quantum spin. This field is fundamental in the interaction of particles with external fields and in many electromagnetic and quantum phenomena.

Two important aspects involved in the magnetic field must be addressed:

ü Movement of a charged particle: An elementary particle with an electric charge, such as an electron or muon, generates a magnetic field when it is in motion. This field is described by Biot-Savart's law, which states that the magnitude and direction of the field depend on the speed of the particle and its charge.

ü Intrinsic magnetic moment (spin): Even when an elementary particle is at rest, it can possess an intrinsic magnetic moment associated with its quantum spin. In the case of the electron, the spin magnetic moment is a fundamental property that influences its interaction with external magnetic fields.

Higgs field

Figure 5. Higgs field. Source: Astronomy.exe

Concept of the Higgs field

It is a fundamental field in particle physics that permeates all space. Its existence was proposed by British physicist Peter Higgs in 1964 as part of an explanation for why some elementary particles have mass, while others do not.

The Higgs field is related to the standard model theory of particle physics, which describes the interactions of subatomic particles. This field is different from other fields in nature, such as the electromagnetic field, in that it not only interacts with charged particles, but also gives mass to particles through its interaction with them.

Relationship between the Higgs field and particle mass

The Higgs field is directly related to the mass of particles. Elementary particles, such as electrons and quarks, obtain mass through their interaction with this field. The intensity with which a particle interacts with the Higgs field determines the magnitude of its mass. The stronger a particle's interaction with the Higgs field, the greater its mass. Below is a graph that demonstrates this relationship:

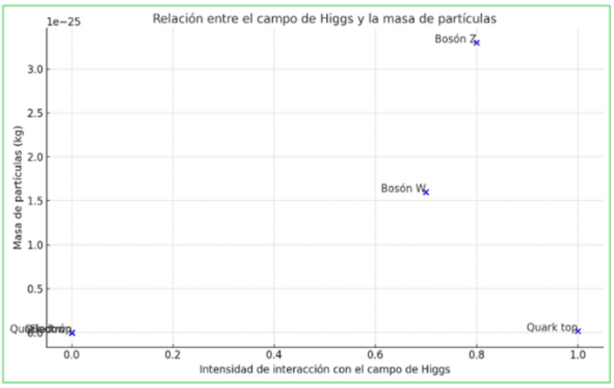


Figure 6. Higgs field and particle mass. Source: Relationship of Higgs bodies.

This phenomenon can be understood by analogy with a particle moving through a field as if it were a person walking through a crowd. If the person interacts a lot with the crowd (with a strong Higgs field), they will move with more difficulty (greater mass). Conversely, if the person interacts less (a weak Higgs field), they will move more easily (less mass).

Spontaneous symmetry breaking mechanism

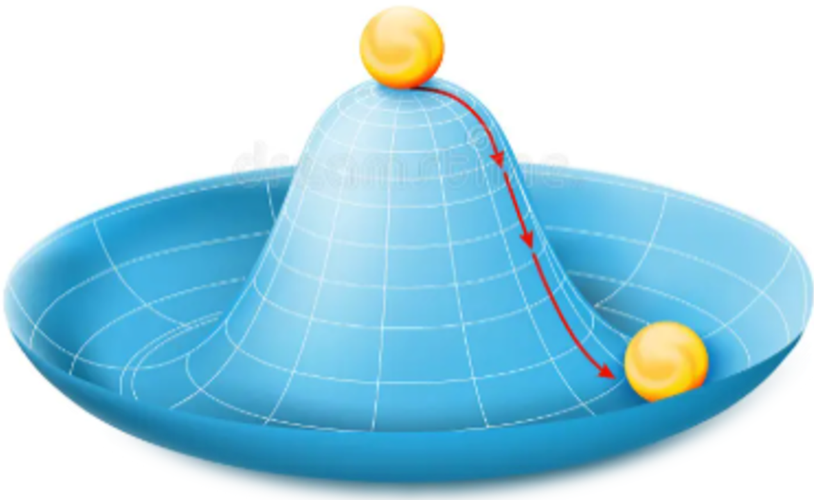


Figure 7. Spontaneous symmetry breaking. Source: Beyond Science

The spontaneous symmetry breaking mechanism is a key concept in particle physics and is fundamental to understanding how the Higgs field gives mass to particles. Symmetry is a property of physical laws that establishes that certain characteristics of the system do not change under specific transformations. In the case of the standard model, the symmetry of fundamental interactions, such as the symmetry between charged and uncharged particles, is maintained at high energies.

However, as the universe cooled after the Big Bang, a spontaneous symmetry breaking occurred. The Higgs field, in its initial state, has perfect symmetry, but when it acquires a non-zero value in the vacuum (the Higgs field "stabilizes" at a value other than zero), this symmetry is broken. This process of spontaneous symmetry breaking causes some particles, such as the Higgs boson, to obtain mass, while others, such as the photon, do not.

This mechanism also explains the emergence of particle interactions with the Higgs field, which is essential for the formation of mass. However, the mechanism of spontaneous symmetry breaking describes how an initially symmetric field can give rise to an asymmetric structure, which, in turn, gives particles physical properties such as mass.

Higgs boson

The Higgs boson is an elementary particle proposed in the Standard Model of particle physics, whose existence was experimentally confirmed in 2012 by the Large Hadron Collider (LHC) at CERN. Its importance lies in its relationship to the Higgs mechanism, which explains the origin of the mass of elementary particles.

Definition and Characteristics

The Higgs boson is a scalar particle, which means it has zero spin. In the Standard Model, it is the quantum excitation of the Higgs field, a field that is omnipresent in the universe. Its mass has been measured at approximately 125 GeV/ (giga electron volts per square of the speed of light).

Due to its short half-life, the Higgs boson decays rapidly into other particles, such as photons, W and Z bosons, and bottom quarks.

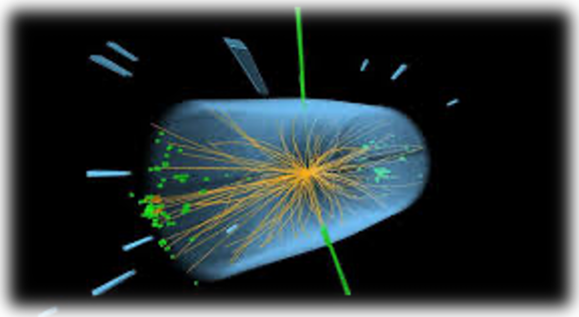


Figure 8. Higgs boson. Source: National Geographic

Another fundamental property of the Higgs boson is its coupling with other particles through the Higgs mechanism, which is related to the spontaneous breakdown of electroweak symmetry. This property allows particles with greater coupling to the Higgs field to acquire greater mass. In addition, its discovery has led to the exploration of new possibilities in particle physics, such as the existence of possible new interactions and theories beyond the Standard Model.

Relationship with the Higgs Field

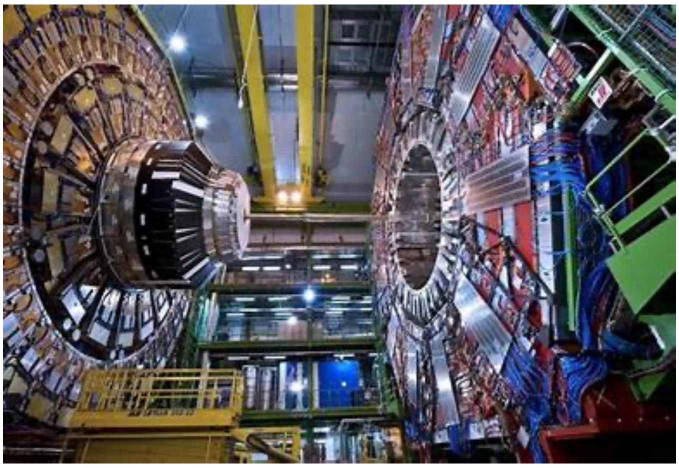
The Higgs field is a scalar quantum field that permeates all space. Through the Higgs mechanism, elementary particles acquire mass by interacting with this field. Without this mechanism, particles such as quarks and leptons would be massless, which would prevent the formation of atoms and, consequently, the existence of the universe as we know it. The discovery of the Higgs boson has been a fundamental experimental confirmation of this mechanism.

The Higgs mechanism is also related to quantum vacuum energy and the stability of the universe. Some theoretical models suggest that the mass of the Higgs boson could be related to the possibility that the universe is in a metastable state, which could lead to a phase transition at extremely high energy scales.

Particle Accelerator

The particle accelerator is a crucial device in scientific research, used to study the structure of matter at the subatomic level. This technology has revolutionized our understanding of the universe, leading to numerous discoveries in physics, chemistry, and biology.

Figure 9. A. of particles. Source: Ok Diario.



The history of particle accelerators dates back to the 1930s. During this period, the first models of linear and circular accelerators were developed. One of the most notable inventors was Ernest O. Lawrence, who created the cyclotron, a type of accelerator that allowed physicists to bombard atomic nuclei and, thus, discover new elements.

As technology advanced, new types of accelerators were developed, such as the synchrotron and the collider. These devices allow much higher energies to be reached, resulting in the generation of new subatomic components.

Description of the LHC and its detectors

The Large Hadron Collider, known as the LHC, is the world's largest particle accelerator. Located on the border between France and Switzerland, it is part of the European Laboratory for Particle Physics, or CERN.

The LHC extends for approximately 27 kilometers. Its design consists of a circular tunnel where protons collide at speeds close to the speed of light. The protons are accelerated through a series of steps in different accelerators before entering the

LHC. One of the most impressive features of the LHC is its ability to collide proton beams traveling in opposite directions. This interaction produces a large amount of energy.

Figure 10. Particle accelerator. Source: InfoEscola

To study the products of these collisions, the LHC is equipped with four main detectors: ATLAS, CMS, LHCb, and ALICE. Each of these detectors has a different focus, optimized to detect different types of particles.

ATLAS (A Toroidal LHC ApparatuS) is one of the largest and most versatile detectors in the world. It is designed to study a wide variety of particles, including those that could indicate the existence of additional dimensions or new forces of nature. On the other hand, CMS (Compact Muon Solenoid) is also a general-purpose detector, although its construction is more compact, allowing data to be obtained in a smaller space.

LHCb (Large Hadron Collider beauty) focuses on flavor physics research, specifically the differences between particles and antiparticles. This is fundamental to understanding the asymmetry between matter and antimatter in our universe. ALICE (A Large Ion Collider Experiment) specializes in heavy ion collisions. This detector studies quark-gluon plasma, a form of matter that existed shortly after the Big Bang.

Particle Collisions

These are interactions that occur when two or more subatomic particles collide with each other. These collisions take place in particle accelerators, such as the Large Hadron Collider (LHC), where atomic nuclei are accelerated to speeds close to that of light before being directed at each other. Studying these collisions allows scientists to investigate the most basic components of matter, such as quarks, electrons, and neutrinos, as well as to explore the fundamental forces: gravity, electromagnetism, strong nuclear force, and weak nuclear force.

Research into particle collisions has been influenced by notable figures such as Richard Feynman, Murray Gell-Mann, and more recently, Fabiola Gianotti, the current director of CERN. Feynman introduced diagrams that simplified the representation of particle interactions. Gell-Mann, for his part, created the classification of quarks. Gianotti has led projects that have achieved significant milestones in the field, becoming a role model for future generations of scientists.

Discovery of the Higgs Boson

The Higgs boson, proposed by physicist Peter Higgs in the 1960s, is a key piece in the Standard Model of particle physics. This theory describes how fundamental particles interact with each other and how they acquire mass through the Higgs mechanism. The existence of the boson provides evidence that the Higgs field, which permeates the entire universe, gives mass to subatomic particles.

One of the most remarkable aspects of the discovery of the Higgs boson is the international effort that went into it. In 1996, construction began on the Large Hadron Collider at CERN, which would become the laboratory where the necessary research to confirm the existence of the boson would be carried out. This particle accelerator, the largest and most powerful in the world, was designed to collide protons at speeds close to that of light, generating conditions similar to those of the early universe. The infrastructure and collaboration of thousands of scientists from various disciplines were essential to the success of the project.

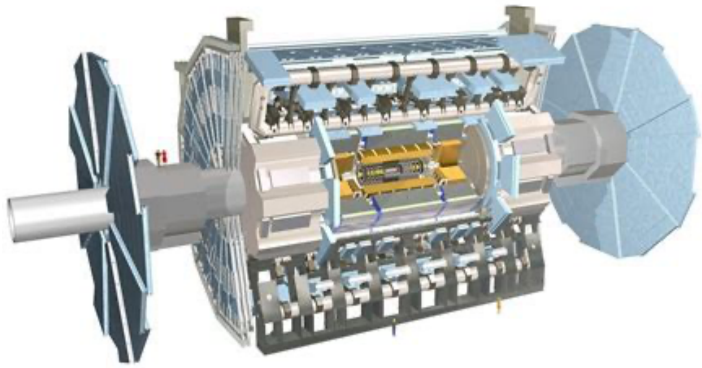


Figure 11. ATLAS experiment. Source: LiveScience

On July 4, 2012, CERN announced the discovery of a particle consistent with the Higgs boson. This finding was received with enthusiasm by the scientific community and marked an outbreak of optimism regarding particle physics. The confirmation of the boson not only validated a long-standing theory, but also became a cornerstone for future research.

The ATLAS and CMS experiments, two of the LHC detectors, conducted exhaustive analyses. For months, scientists reviewed the data, looking for additional evidence. Finally, in March 2013, the discovery was considered definitive when properties of the boson were measured that matched the predictions of the Standard Model. This was a moment of intense excitement and celebration in the scientific community.

Higgs boson

Experimental confirmation of the Higgs boson

The Higgs boson, proposed theoretically in 1964 by Peter Higgs and others, is a fundamental particle that explains how other particles acquire mass through the Higgs mechanism. Its existence was experimentally confirmed on July 4, 2012, by CERN, using the Large Hadron Collider (LHC). The ATLAS and CMS experiments detected a new particle with a mass around 125 GeV/c^2, consistent with the predictions of the Higgs boson. This discovery validated an essential piece of the Standard Model of particle physics.

Limitations of the Standard Model

Although the Standard Model has been successful in describing fundamental interactions and known elementary particles, it has several limitations:

Ø Gravity: It does not incorporate gravitational interaction, since general relativity, which describes gravity, is not integrated into the quantum framework of the Standard Model.

Ø Dark matter and dark energy: It does not provide an explanation for dark matter and dark energy, which make up most of the universe.

Ø Neutrinos: It does not adequately explain the properties of neutrinos, such as their masses and oscillations.

Ø Matter-antimatter asymmetry: It does not address the reason why the observable universe is composed mainly of matter, even though the Big Bang is expected to have produced equal amounts of matter and antimatter.

These limitations suggest the need for theories beyond the Standard Model to fully describe fundamental physics.

How do we know if there is a Higgs in the data taken in the CIMA (CMS Instrument for masterclass analysis) simulator?

CIMA is an educational tool that allows students and enthusiasts to analyze real data from the CMS experiment at the LHC. To identify events that could correspond to the Higgs boson, the following steps are taken:

· Event selection: The data is filtered to select events with specific characteristics, such as the presence of two high-energy photons or four leptons (electrons or muons), which are common signatures of Higgs boson decay.

· Reconstruction of invariant masses: From the detected particles, the invariant mass of the system is calculated. A peak around 125 GeV/c² in the invariant mass distribution indicates the possible presence of the Higgs boson.

· Statistical analysis: Statistical analyses are performed to distinguish the Higgs boson signal from the background of other physical processes.

This approach allows CIMA users to experience the discovery and analysis process that led to the confirmation of the Higgs boson in 2012.

Data acquisition method

The table below shows the results obtained in the 100 events, distributed as follows: Table 1 events 1 to 31; Table 2 events 32 to 60; Table 3 events 61 to 90; and Table 4 events 91 to 100.

Table 1. *Data obtained from CIMA*

Event index	Event number	Final state	Primary state	Mass
6001	10.1-01	uv	W-	
6002	10.1-02	*ev*	W+	
6003	10.1-03	4μ	W+	
6004	10.1-04	uv	W-	
6005	10.1-5	uv	W+	
6006	10.1-6	*ev*	W-	
6007	10.1-7	*ee*	Partícula neutra (Z, H)	44,84

6008	10.1-8	2u2e	Partícula neutra (Z, H)	44,84
6009	10.1-9	ev	W+	
6010	10.1-10	*μμ*	neutral	90.33
6011	10.1-11	*μν*	W+	
6012	10.1-12	2e	neutral	88.35
6013	10.1-13	2e 2μ	Partícula neutra (Z, H)	228.79
6014	10.1-14	*μν*	W-	
6015	10.1-15	*ev*	W+	
6016	10.1-16	μν	W+	
6017	10.1-17	ev	W+	
6018	10.1-18	*ev*	W+	
6019	10.1-23	*2e*	Partícula neutra (Z, H)	2.28
6020	10.1-20	2e	Partícula neutra (Z, H)	88.35
6021	10.1-21	μν	W+	
6022	10.1-22	*ev*	W-	
6023	10.1-23	*μμ*	Partícula neutra (Z, H)	5.46
6024	10.1-24	μμ	Partícula neutra (Z, H)	9.72
6029	10.1-29	ev	W-	
6030	10.1-30	*μν*	W-	
6031	10.1-31	*μν*	W-	

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The results in Table 2 reflect events from 32 to 60.

Table 2. *Data obtained from CIMA*

Event index	Event number	Final state	Primary state	Mass
6032	10.1-32	2e	neutral	6.87
6033	10.1-33	4u	W+	
6034	10.1-34	*ev*	W-	
6035	10.1-35	*4u*	Partícula neutra (Z, H)	44,84
6036	10.1-36	uv	Partícula neutra (Z, H)	44,84
6037	10.1-37	uv	W-	
6038	10.1-38	*ev*	W+	
6039	10.1-39	*4μ*	W+	
6040	10.1-40	uv	W-	
6041	10.1-41	4μ	W-	
6042	10.1-42	ev	Zoo	
6043	10.1-43	μv	W+	
6044	10.1-04	4μ	W-	
6045	10.1-45	uv	W-	
6046	10.1-46	*ev*	W+	
6047	10.1-47	*4μ*	W+	
6048	10.1-48	uv	W-	
6049	10.1-49	2e2μ	neutral	178,72
6050	10.1-50	*4μ*	W+	
6051	10.1-51	*4μ*	W+	
6052	10.1-52	4μ	W-	
6053	10.1-53	μv	w-	
6054	10.1-54	ev	w+	
6055	10.1-55	μμ	w-	
6056	10.1-56	μμ	w-	
6057	10.1-57	ev	W+	
6058	10.1-58	*uv*	W-	
6059	10.1-59	*2e*	W+	
6060	10.1-60	uu	W-	

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The results in Table 3 reflect events from 61 to 90.

Table 3. *Data obtained from CIMA*

Event index	Event number	Final state	Primary state	Mass
6061	10.1-61	μν	W-	
6062	10.1-62	μν	W+	
6063	10.1-63	4e	W-	
6064	10.1-64	μμ	W±	
6065	10.1-65	eν	W-	
6066	10.1-66	μν	W+	
6067	10.1-67	eν	W+	
6068	10.1-68	μμ	neutral	3.71
6069	10.1-69	μν	W+	
6070	10.1-70	μν	W+	
6071	10.1-71	μν	W+	
6072	10.1-72	2e 2μ	neutral	128.94
6073	10.1-73	2e	neutral	87.15
6074	10.1-74	2e 2μ	neutral	232.96
6075	10.1-75	μν	w+	
6076	10.1-76	4μ	neutral	233.29
6077	10.1-79	eν	W-	
6078	10.1-78	μν	W+	
6079	10.1-77	eν	W+	
6080	10.1-80	eν	W+	
6081	10.1-81	μν	W+	
6082	10.1-82	4μ	Neutral	502.13
6083	10.1-83	μν	W+	
6084	10.1-84	4e	W+	
6085	10.1-85	2e	neutral	10.24
6086	10.1-86	eν	W+	
6087	10.1-87	2e 2μ	W+-	
6088	10.1-88	2e 2μ	W+-	
6089	10.1-89	4μ	Neutral	87.71
6090	10.1-90	2e 2μ	W+	

Prepared by: Research group

The results in Table 4 reflect events from 91 to 100.

Table 4. *Data obtained from CIMA*

Event index	Event number	Final state	Primary state	Mass
6091	10.1-91	ev	W+-	
6092	10.1-92	uv	W-	
6093	10.1-93	*ev*	W+	
6094	10.1-94	*4μ*	W+	
6095	10.1-95	2e 2μ	W+	
6096	10.1-96	4e	W-	
6097	10.1-97	4μ	W+-	
6098	10.1-98	2e	Partícula neutra (Z, H)	0,11
6099	10.1-99	*4e*	W+	
6100	10.1-100	*uu*	W-	

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From this, the following results are obtained:

Of the 100 cases analyzed, a lepton called an electron neutrino (ev), composed of an electron and a neutrino, was identified in 23 of them. Of these cases, 7 correspond to the W- particle (with counterclockwise rotation), 15 to the W+particle (with clockwise rotation), and 2 to the W+- particle.

When pairs of identical particles propagating in opposite directions are detected, the presence of a neutral particle is inferred, since the charges cancel each other out, maintaining the conservation of electric charge.

Of the 100 data points, 13 Z bosons were obtained, which are distributed in pairs of leptons: 8 electron-positron () and 5 muon-antimuon (). Being neutral, their decay products conserve the net charge in the process.

· decays into an electron () and its antiparticle, the positron (), maintaining charge conservation.

· decays into a muon () and an antimuon (), another common decay channel of the Z boson.

These processes are due to the neutral weak interaction, where the Z boson mediates the interaction without changing the identity of the leptons.

· Some images obtained in the simulator showed that the collision between protons generates the most important elementary particle called the "Higgs boson," which has an average lifetime of , a width of 4 MeV, and a mass of 125.2 GeV, which is equivalent to the total energy possessed by the particle. Furthermore, when this particle decays, there are two possible outcomes: the first is into two neutral bosons (which decay into four muons), and the second is into two photons. In this case, the simulator was limited to detecting the Higgs boson through the first possibility.

Using the Cima simulator, it was identified that in the experimental data collection there were 15 Higgs bosons (i.e., of the 100 events that took place, only 15 of those events gave rise to this neutral particle). With that said, when two protons collide with sufficient energy, at that moment of interaction between quarks and gluons, it is unlikely that this neutral particle will appear (and much more likely that charged bosons will be generated W^+), (W^-), o (Z^0).

Conclusions

The CIMA simulator allowed us to relate these particles, facilitating the observation of their trajectories, lifetimes, and behaviors in different collisions between elementary particles, their interaction, and how they transform their energy into measurable products, thus contributing to the understanding of the Standard Model of Particle Physics.

The Standard Model of particle physics is the theory that describes fundamental particles and fundamental forces. The Standard Model is divided into:

Ø Fermions (constitute matter): Quarks and Leptons.

Ø Bosons (force mediators):

Ø W^+, W^-, and Z^0 bosons: mediators of the weak interaction.

Ø Higgs boson (H): responsible for giving mass to particles through the Higgs mechanism.

The W^+, W^-, and Z^0 bosons are fundamental to the weak force, which is responsible for processes such as radioactive decay.

Ø Z^0 boson → Mediates neutral interactions, where particles interact without changing type.

Ø W^+ and W^- bosons → Responsible for charged weak interactions, where a particle changes type (flavor change).

The Standard Model unifies electromagnetic interaction and weak interaction into a single theory, called the electroweak theory.

Finally, the Cima simulator experiment confirmed the existence of Higgs bosons () by collecting data in the final table, and in the same way, thanks to the standard model of particle physics, we were able to understand the relationship between quarks, leptons, and bosons, where the principle of conservation of mass and charge is fulfilled regardless of the interaction between them at the moment of collision between protons.

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