

Research on the Basic Principle and Technical Development of the Large Hadron Collider

Zizheng Zuo

Shenzhen College of International Education, Shenzhen, China

s20024.zuo@stu.scie.com.cn

Abstract. LHC (Large Hadron Collider) is a kind of high-energy physics experimental equipment, which consists of a series of superconducting magnets, accelerators and other equipment. It can accelerate charged particles to near the speed of light, and generate and detect new particles in high-energy collisions. This paper introduces the basic principle and technical development research of LHC. Firstly, this paper introduces the basic function and operation mechanism of LHC, focusing on how to accelerate particles to near the speed of light through two stages of linear accelerator and ring accelerator, and how to carry out high-energy particle collision experiments at the collision point. Secondly, in view of the technical challenges of LHC, this paper discusses how to solve the problems of acceleration and focusing of high-energy particles, design and construction of detectors, and maintenance of high vacuum and low temperature environment. Finally, this paper summarizes the influence and achievements of LHC, including promoting the development of particle physics, promoting the development of science and technology and stimulating public interest in science. At the same time, it expounds in detail its important achievements in discovering the Higgs boson and other new physical phenomena and its understanding of the origin and evolution of the universe. In order to contribute to related fields.

Keywords: Large Hadron Collider, Particle physics, Accelerator.

1. Introduction

Particle physics is a scientific field that studies the most basic components of the universe and the nature of force. Its research depth has exceeded the scope of atoms and molecules and entered the world of quarks, leptons, gluons and other particles [1]. In order to explore these particles and their interactions, an experimental device named LHC was established, which is one of the most important research tools in particle physics [2]. As early as the 1980s, the concept of LHC had begun to take shape. At that time, scientists already knew that the four basic forces in the universe-gravity, electromagnetic force, strong nuclear force and weak nuclear force-could be described by quantum mechanics [3]. However, although these theories can give correct predictions in many cases, they cannot explain some phenomena, such as the origin of mass and some characteristics of particles [4]. Therefore, scientists hope to further reveal the answers to these questions through particle collision experiments with higher energy. LHC was born in this context. As the largest particle accelerator in the world, LHC began to operate in 2008, and its goal is to study the properties and interactions of particles at higher energy, in order to find new physical phenomena and explain problems that cannot be explained by current theories [5].

LHC is one of the most important research tools in particle physics, which plays a vital role in revealing the most basic components of the universe and the nature of forces [6]. The purpose of this paper is to discuss the basic principle and technical development of LHC comprehensively and deeply, and to show its important contribution to modern particle physics and the whole scientific community. This paper will first introduce the basic principle of LHC, including its function, operation mechanism and contribution to physics. Then it discusses the technical challenges faced by the construction and operation of LHC and how to solve these challenges; Finally, the scientific achievements and influence of LHC will be discussed, including the basic particles and new physical phenomena that have been discovered. By reading this article, readers will have a deep understanding of all aspects of LHC, from basic principles to technical development, to scientific achievements and future

development plans. I hope this research can provide readers with useful reference and enlightenment and help them better understand the nature and laws of the universe.

2. The basic principle of LHC

LHC is a key experimental device in particle physics (see Figure 1). It consists of a series of superconducting magnets, accelerators and other equipment, which can accelerate charged particles to near the speed of light, and then generate and detect new particles in high-energy collisions [7]. This section will introduce the basic principle of LHC, including its function and operation mechanism.

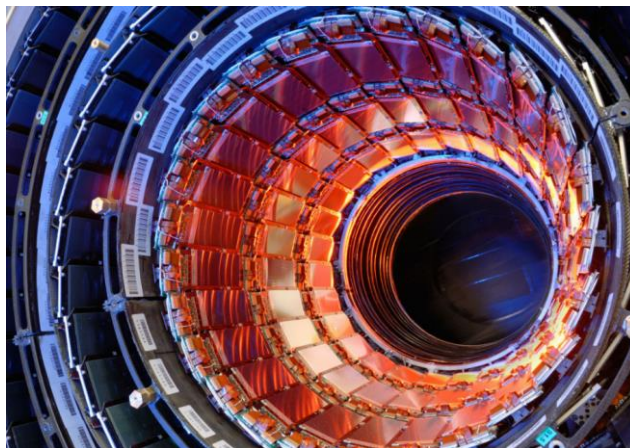


Figure 1. LHC

2.1. Function

The main function of LHC is to carry out high-energy physics experiments, study particle collisions and find new physical phenomena [8-9]. It simulates the early cosmic conditions after BIGBANG by accelerating charged particles to near the speed of light and then guiding them to collide in a high vacuum ring. This simulation is of great significance for understanding the origin, structure and evolution of the universe.

2.2. Operating mechanism

The working principle of LHC is based on the combination of a linear accelerator and a ring accelerator. Linear accelerators accelerate charged particles from a static state to a certain speed, and then guide them into a ring accelerator. The ring accelerator is composed of a series of superconducting magnets, which can provide a high-intensity magnetic field to accelerate particles in the ring until they reach a speed close to the speed of light (see Figure 2). At the collision point, two beams collide, producing a large number of new particles. The kind and quality of these particles can be measured and recorded by the detector system. LHC has extremely high accuracy and sensitivity, and can detect tiny particle signals and convert these signals into scientific data for physicists to analyze and study.

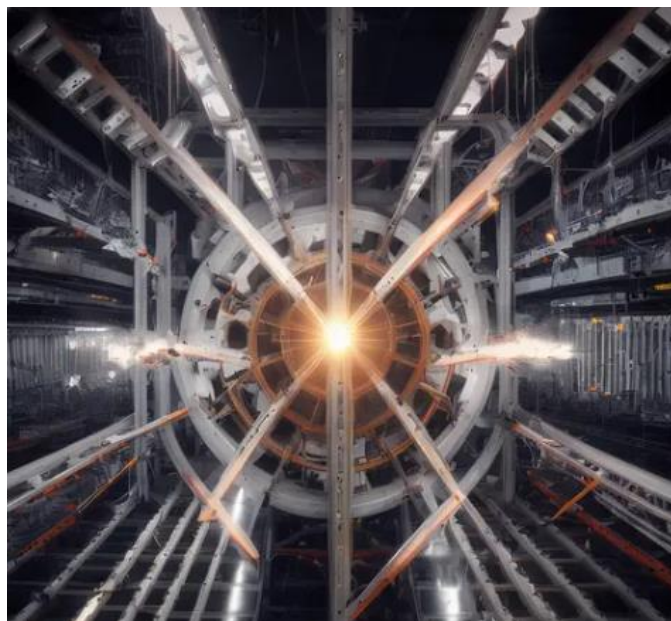


Figure 2. Operation mechanism of large hadron collider

Through this operating mechanism, LHC can simulate the conditions of BIGBANG's post-early universe, so that we can better understand the origin, structure and evolution of the universe. At the same time, through high-energy particle collision experiments, physicists can study the interaction between particles and the origin and evolution of the universe, discover new basic particles and physical phenomena, and thus promote human understanding of the nature of the universe and matter. It should be noted that LHC will produce a large amount of data during its operation, and the processing and analysis of these data require high-performance computing and storage systems and complex analysis software. At the same time, in order to ensure the accuracy and reliability of the experimental results, strict experimental design and data analysis quality control are needed. Therefore, the successful operation of LHC requires not only advanced experimental equipment and technical support, but also in-depth research and analysis by physicists.

3. Technical challenges and solutions of LHC

This section will discuss the technical challenges in building and operating LHC and how to solve them.

3.1. Technical challenges

(1) Acceleration and focusing of high-energy particles

LHC needs to accelerate charged particles to near the speed of light, and at the same time, it needs to maintain the stability and quality of particle beam at extremely high energy density [10]. This requires the use of advanced accelerator technology, such as superconducting accelerator and magnetic focusing system. The application of these technologies has brought many technical challenges, such as how to improve the efficiency of the accelerator, how to accurately control the size and shape of the particle beam, and how to deal with the energy loss of high-energy particles.

(2) Design and construction of detector

LHC needs a series of high-performance detectors to measure and record the products of high-energy particle collisions. These detectors must have high accuracy, sensitivity and stability to distinguish background noise from real physical signals. In addition, the design and construction of the detector are also faced with challenges such as how to improve the coverage of the detector, how to reduce instrument errors, how to process a large amount of data and how to realize real-time data processing.

(3) Maintenance of high vacuum degree and low temperature environment

LHC needs to operate in extremely high vacuum and low temperature environment to reduce background noise and improve the sensitivity of the experiment. However, to maintain this environmental condition, many technical problems need to be overcome, such as how to avoid the interaction between particle beam and gas molecules, how to seal and clean the experimental ring, and how to control and monitor the experimental environment.

3.2. Solutions

As mentioned above, LHC faces three technical challenges, including the acceleration and focusing of high-energy particles, the design and construction of detectors, and the maintenance of high vacuum and low temperature environment. In view of these problems, the following corresponding solutions can be adopted:

(1) Superconducting accelerator and magnetic focusing system are used to accelerate and focus high-energy particles. These systems make use of the characteristics of superconducting materials to generate and maintain a strong magnetic field for accelerating and focusing charged particles. At the same time, in order to solve the stability problem of particle beam size and shape, scientists have also developed an advanced feedback control system to adjust the shape and intensity of magnetic field in real time to ensure the stability of particle beam. In addition, for the problem of particle energy loss, the energy loss of particles is reduced by optimizing the accelerator structure.

(2) For the design and construction of the detector, the first problem to be solved is the accuracy, sensitivity and stability of the detector. In order to improve the accuracy and sensitivity of the detector, scientists have adopted advanced signal processing techniques and data analysis algorithms, such as digital signal processing and field programmable gate array, which can process a large number of particle signal data quickly and accurately. At the same time, in order to reduce the instrument error and improve the stability of the detector, precise mechanical design and stable low-temperature working environment are adopted, such as using ultra-low temperature coolant such as liquid helium in the detector to reduce interference factors such as thermal noise.

(3) For the maintenance of high vacuum and low temperature environment, scientists have adopted high vacuum technology and low temperature cooling technology. Firstly, a high vacuum environment is realized by using high-performance vacuum pump and strict sealing measures in the experimental ring. At the same time, the low temperature environment of the experimental ring is maintained by using ultra-low temperature coolant such as liquid helium and other special designs. In addition, a real-time monitoring and feedback system is adopted to detect and solve possible environmental problems in time by monitoring environmental parameters in real time, thus ensuring the stability of the experimental environment.

These solutions not only successfully overcome the technical challenges faced by LHC, but also promote the development and innovation of science and technology, which is of great scientific value for understanding the basic particles and forces of the universe.

4. The influence and achievements of LHC

This section will discuss the influence and achievements of LHC, including its new physical phenomena and its significance for understanding the universe.

4.1. Influence

(1) Promote the development of particle physics

LHC is of great significance for understanding the basic particles and forces in the universe. Physicists can study the interaction between particles and the origin and evolution of the universe through high-energy particle collision experiments. For example, the Higgs boson was discovered in the LHC, and this discovery was awarded the 2013 Nobel Prize in Physics. In addition, LHC has discovered many other elementary particles and new physical phenomena, such as supersymmetric

particles and pentaquark states. These discoveries are of great scientific value for deeply understanding the nature and laws of the universe.

(2) Promoting the development of science and technology

The construction and operation of LHC involves a series of high-tech equipment and technologies, such as superconducting magnets, accelerators and detectors. The application of these technologies has promoted the technological development in related fields, such as superconducting technology, vacuum technology and low temperature technology.

(3) Stimulate public interest in science

The experimental results and scientific goals of LHC have attracted the attention of science lovers all over the world. The mysteries of the universe revealed by LHC and the exploration spirit of scientists have aroused the public's interest and enthusiasm for science.

4.2. Achievements

(1) The discovery of the Higgs boson

The most important achievement of LHC is the discovery of the Higgs boson. Higgs boson is a key part of Higgs mechanism, which explains why particles such as protons and neutrons have mass. This discovery not only verifies the prediction of the standard model, but also provides important clues for studying the origin and evolution of the universe.

(2) Exploration of new physical phenomena

LHC's high-energy particle collision experiment also found many new physical phenomena. For example, it has discovered new particles such as five quark states, and the discovery of these particles is of great significance in particle physics. In addition, LHC has also explored some new physical phenomena beyond the standard model, such as the study of extra dimensions. These explorations provide a new perspective for understanding the basic particles and forces of the universe.

(3) Understanding of the origin and evolution of the universe

LHC has further deepened our understanding of the origin and evolution of the universe through the study of high-energy particle collisions. For example, it reveals the function of Higgs mechanism in the universe and explains why matter in the universe has mass. In addition, LHC also provides clues for us to understand the evolution of the universe by studying the discovery of new particles.

The influence and achievements of LHC are various. It not only promotes the development of particle physics and science and technology, but also stimulates the public's interest in science. At the same time, its experimental results and new discoveries also provide important clues and perspectives for us to understand the origin and evolution of the universe. However, although LHC has made many achievements, it is still a developing experimental project, and it is expected that it will bring more scientific discoveries and innovations in the future.

5. Conclusion

In this paper, the basic principle, technical development, influence and achievements of LHC are deeply discussed. As an important tool of contemporary particle physics research, LHC not only promotes the development of particle physics, but also promotes the development of science and technology and the public's enthusiasm for science. First of all, through its unique design and advanced operating mechanism, LHC successfully accelerates and focuses charged particles, causing them to collide at extremely high energy density, thus generating and detecting new particles. This process not only reveals the existence and properties of new particles such as Higgs boson, but also provides important clues to deeply understand the basic particles and forces of the universe. Secondly, the construction and operation of LHC involves a series of high-tech equipment and technologies, such as superconducting magnets, accelerators and detectors. The application of these technologies has promoted the technological development in related fields, such as superconducting technology, vacuum technology and low temperature technology. Finally, the results of LHC not only have important application value in particle physics, but also have important scientific value for

understanding the origin and evolution of the universe. The results of its high-energy particle acceleration and collision experiments not only reveal the existence and properties of new particles such as Higgs boson, but also provide important clues and perspectives for deeply understanding the basic particles and forces of the universe and the origin and evolution of the universe.

In the future, with the continuous progress of technology and the deepening of research objectives, LHC will continue to play a central role in particle physics and cosmology research, and further promote human understanding of nature. At the same time, with the continuous development of science and technology, it is expected that LHC will find more new physical phenomena in future research and make greater contributions to human scientific progress.

References

- [1] Gao Y. Experimental progress on the Large Hadron Collider [J]. *Physics*, 2019, 48(5): 4.
- [2] Gong Xi. Study on Pseudorapidity and Energy Estimation on the Large Hadron Collider [J]. *Journal of Jiangxi Normal University: Natural Science Edition*, 2020, 44(6): 5.
- [3] Tan Z. Energy multiplicity of proton-proton collisions in the Large Hadron Collider [J]. *Journal of Changsha University*, 2019, 33(5): 3.
- [4] Qin G. Soft probe and hard probe in relativistic heavy ion collisions [J]. *Review of Nuclear Physics*, 2020, 37(3): 12.
- [5] Zheng X. Talking about the dead angle effect in quantum chromodynamics [J]. *University Science*, 2022, 16(4): 13-13.
- [6] Wu Z, Jiang J, Xia D, et al. Research on energy meter detection unit based on domestic SiPM [J]. *nuclear electronics and detection technology*, 2019, 39(6): 5.
- [7] Shen C, Fang Y, Ruan M. Research on particle physics in collider experiment [J]. *Journal of Liaoning Normal University: Natural Science Edition*, 2018, 41(3): 9.
- [8] Jin S, Xu Q. Frontier Technology in Large Ring Collider [J]. *Modern Physics Knowledge*, 2020, 32(1): 9.
- [9] Li W, Wang M, Zhu Z, et al. Preliminary Study on Siphon Experiment of Superconducting Magnet in Large Detector of Ring Electron Positron Collider [J]. *Cryogenic Engineering*, 2017(1): 5.
- [10] Zhou X. Three new exotic particles were discovered in the Large Hadron Collider [J]. *Reliability and Environment Test of Electronic Products*, 2022, 40(4): 34-34.