

Teachers' Guide

Collider

世紀實驗：STEP INSIDE THE WORLD'S GREATEST EXPERIMENT

探索神秘的粒子世界

18.3 – 25.5.2016

聯合主辦
Jointly presented by



蔡冠深基金會
Jonathan KS Choi Foundation

聯合籌劃
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香港中文大學物理系
Department of Physics
The Chinese University of Hong Kong

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Introduction

The technological advances of science and technology are making continuous improvements to the lives of mankind, e.g. the application of the internet allows people to get closer to each other, the development of Magnetic Resonance Imaging has resulted in new methods of medical diagnosis and therapy, and the power of computers is enhancing the efficiency of data processing on a massive scale in various industries. Have you ever considered that all of these cutting-edge technologies are derived from studies in the field of particle physics?

There are thousands of unsolved mysteries throughout our colossal universe. Over the years, scientists have endeavoured to unveil the origin of the universe and discover the basic constituents of matter. The European Organization for Nuclear Research (CERN) is a multinational organisation ran by twenty one member states. It has been gathering thousands of top scientists and engineers from around the world, who designed and built the Large Hadron Collider (LHC) that is located across the border between Switzerland and France. LHC is the world's largest and most powerful particle accelerator. It consists of a 27-kilometre ring of superconducting magnets. Inside the collider, scientists carry out experiments by colliding two high-energy particle beams which travel at close to the speed of light. By analysing the data obtained, scientists are able to reveal clues about how particles interact and gain an insight into the underlying mysteries of the universe.

This exhibition recreates the working environment and laboratories of the scientists at CERN, allowing visitors to enjoy an immersive experience and learn about the objective of this advanced project. They can also witness the discovery of the God Particle (Higgs boson) and gain an understanding of the fundamental theories of particle physics. Exhibit highlights include multimedia programmes, animations, real components that have been used at CERN such as a 2-tonne superconducting magnet, as well as some scientific equipment collected by the Science Museum in London. Furthermore, the exhibition also provides an introduction to the achievements of local researchers who have been actively participating in the work of this greatest experiment in the world, and shares the challenges they have faced during the studies.

Jointly presented by Leisure & Cultural Services Department and Jonathan KS Choi Foundation

Jointly organised by Hong Kong Science Museum and

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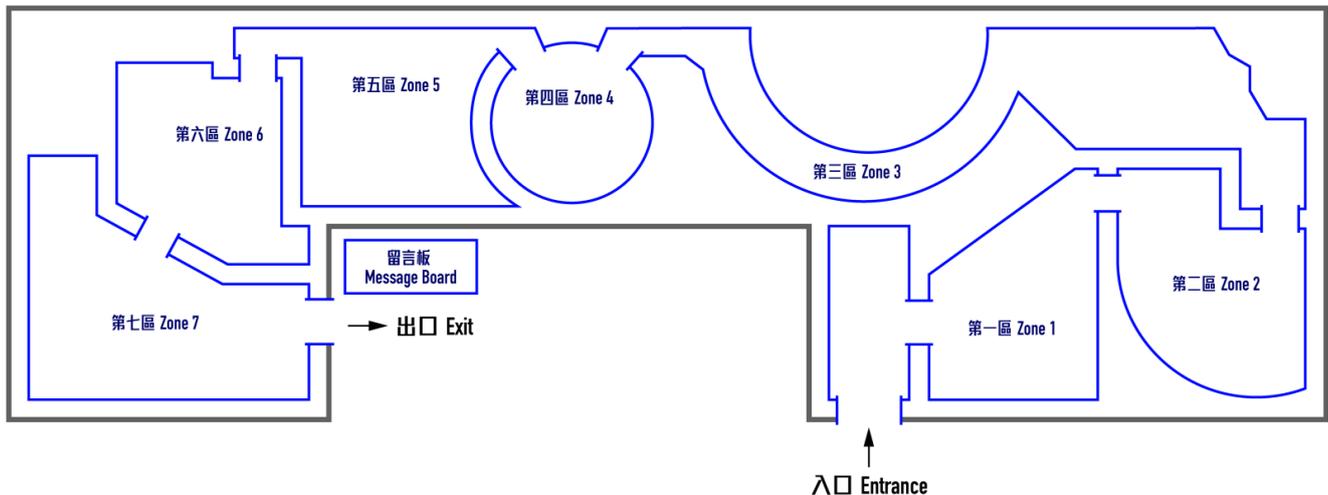
Exhibition is produced by Science Museum in London

Information on Visits

Exhibition Period: 18.3.2016 – 25.5.2016

Venue: Special Exhibition Hall, Hong Kong Science Museum

Floor Plan



Zone 1: The Past and the Present

This area introduces the development and history of particle physics. We can see how particle physicists discovered various particles and the instruments used.

Zone 2: CERN Theatre

Meet the scientists and share their joy of Higgs boson's discovery.

Zone 3: The LHC

Buried deep in the ground, the Large Hadron Collider reveals itself right in front of your eyes. You can learn about its working principles and even meet the scientists and engineers.

Zone 4: The Collision

Although we cannot witness the collision with our naked eyes, we can imagine the majestic picture created during the collision.

Zone 5: The Detectors

The LHC is equipped with four gigantic detectors: LHCb, ALICE, CMS and ATLAS. Their components are extremely complex, but some of them are made from common materials like glass and fishing lines.

Zone 6: The Discovery and the Future

Step into the office of the scientists. Take a look at their work and witness the discovery of the Higgs boson. The Higgs boson is not the end of the journey. Let's wait and see what the future may bring us.

Zone 7: Particle Physics 101

Scientists from Hong Kong have also taken part in LHC projects, performing various researches and experiments. Let's take a look at their contributions and their daily lives at CERN, and learn more about the basic concept of particle physics.

Working Principles of the Large Hadron Collider (LHC)

Through multimedia programmes, simulated laboratory environments, real components that have been used at CERN, etc., this exhibition allows visitors to learn the working principles of the LHC.

The diagram below shows how the LHC beams are made and protons are accelerated and collided.

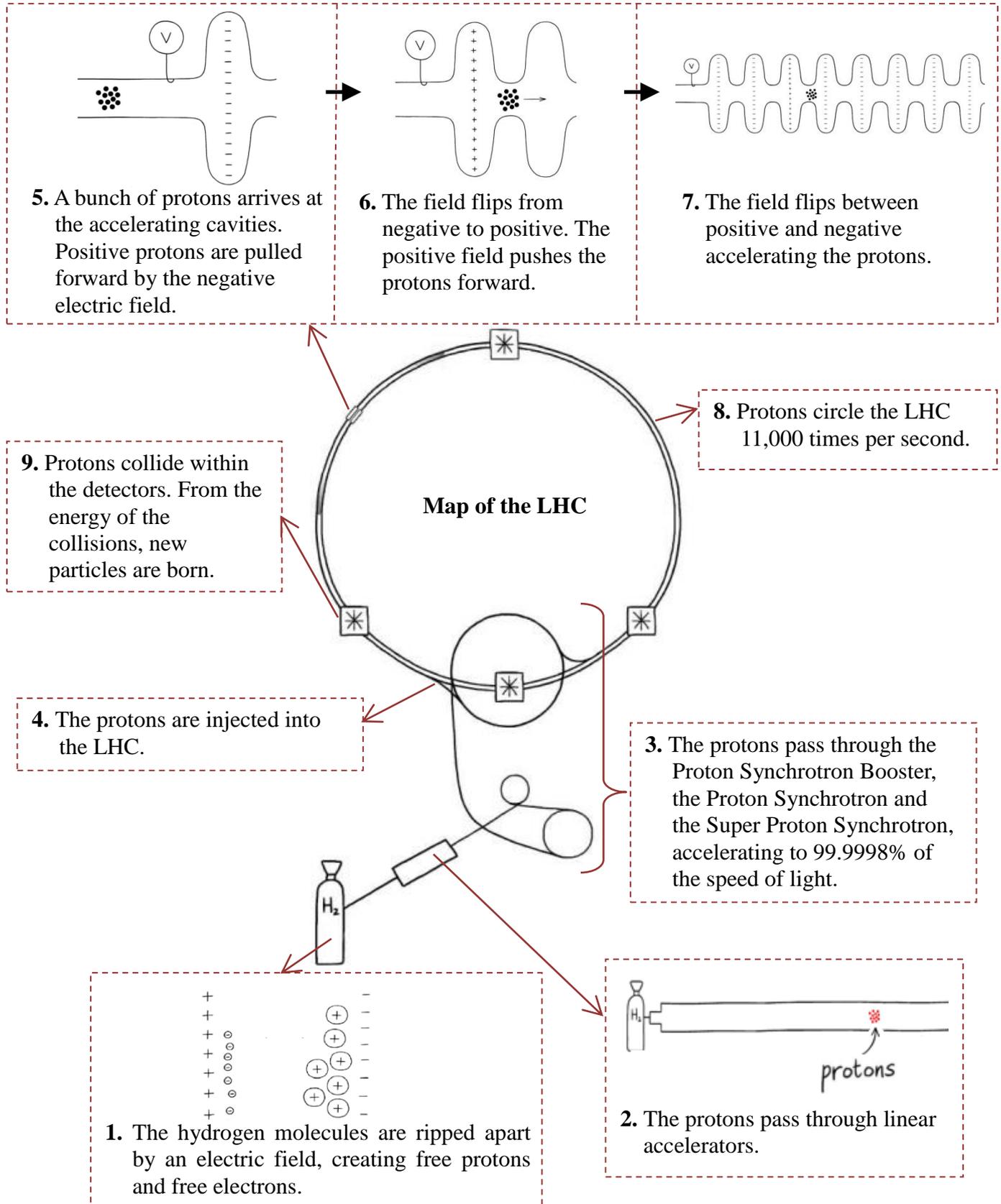
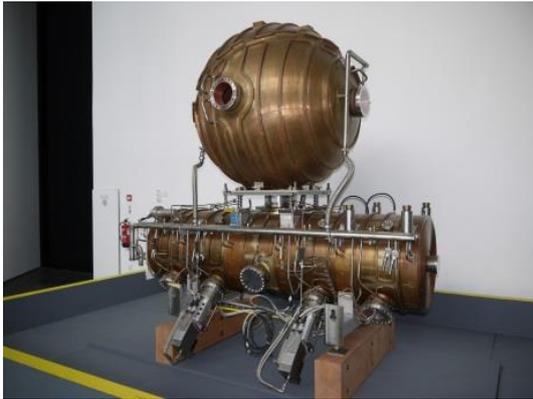
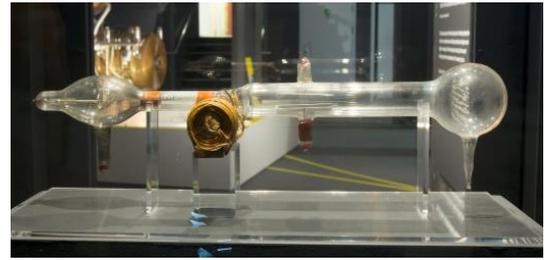


Exhibit Highlights



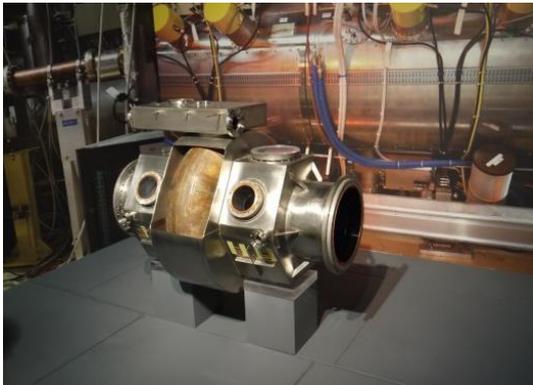
Large Electron-Positron (LEP) Collider Accelerating Cavity

Before the LHC, CERN scientists used this apparatus to conduct particle physics experiments.



Cathode-ray Tube

This apparatus was used by J J Thomson during the discovery of electrons in 1897.



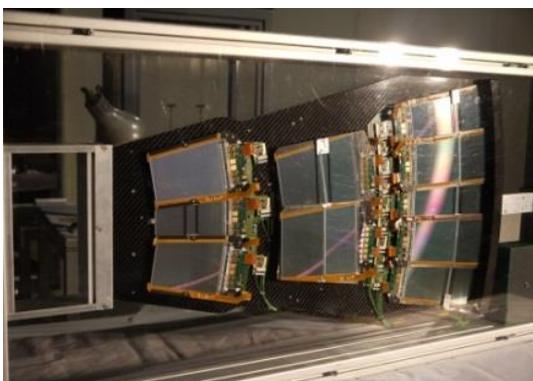
Large Hadron Collider (LHC) Accelerating Cavity

It generates a two-million-volt electric field and increases the energy of passing protons.



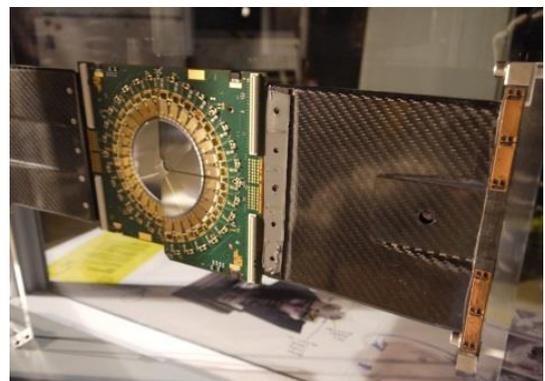
Focusing Magnet

This quadrupole magnet is used for squeezing the beams, making them narrower and more condensed, thus increasing the collision rate.



Silicon Tracker Petal

This module is able to withstand the intense particle collisions and track the path of the particles.



Vertex Locator (VELO) Modules

Don't look down on this small detector module. During collision, the distance between the collision point and this module is only a mere seven millimetre!

Standard Model of Particle Physics

Everything in the universe is found to be made from a few basic building blocks called fundamental particles, governed by four fundamental forces. From our understanding to particle physics, the Standard Model explains how these particles (protons, neutrons and electrons) and three of the forces (electromagnetic force, strong force and weak force) are related to each other. In July 2012, the physicists of CERN successfully discovered the Higgs bosons, the last piece of puzzle of the Standard Model, using LHC.



Quarks

There are six types of quarks in the standard model, and only quarks react with strong force. Any particle made of quarks is called a hadron. When three quarks combine, they form baryons, such as protons and neutrons. When two quarks combine, they form mesons, for instance, pion.

Leptons

In parallel, there are six types of leptons, and they do not react to strong force. The most familiar member of the lepton family is the electron, which is the charge carrier in electric current. In Greek, the word 'lepton' means light in mass, but it is found that some leptons in fact are not light.

Fundamental Forces and Gauge Bosons

There are four fundamental forces governing matter in the universe – gravity, electromagnetic force, strong force and weak force. Gauge bosons are the force carriers, which act as the way of transmission. Leptons and quarks interact by exchanging gauge bosons to form all the known subatomic particles – the basic ingredients of normal matter.

Gauge bosons determine the properties of the fundamental forces. Photons carry electromagnetic force and interact with charged particles. Gluons interact with quarks and hadrons with strong force and bind protons and neutrons in the atomic nucleus. W and Z bosons interact with all quarks and leptons with weak force. So far physicists have not been able to describe the fourth fundamental force, gravity, in the same way as the other three forces.

Higgs Boson

Particles with mass move at a speed below the speed of light, while massless particles move at the speed of light. Elementary particles in the standard model have a wide range of masses, while photons and gluons are massless. The Higgs mechanism was proposed in 1964 to address the origin of these masses. A field – the Higgs field – is theorised to fill the vacuum. Elementary particles - massless originally - propagating through the vacuum would then be dragged by the Higgs field and slowed down, hence behaving like massive particles with large inertia.

The Higgs field interacts with all leptons, quarks, and the W and Z gauge bosons. Photons and gluons do not interact with the Higgs field and so remain massless, whereas particles like the top quark, W and Z bosons interact much more with the Higgs field and acquire large masses. This theory predicts the existence of the Higgs boson, an excited state of the Higgs field. Throwing a pebble into still water will create ripples.

Dark Matter

There are three levels of structures in the uneven distribution of matter in the universe. Stars are bound gravitationally to form galaxies and a group of galaxies form galaxy clusters. A galaxy revolves around the centre of mass of its galaxy cluster, and the orbital speed is related to the matter distribution within the clusters. Observations have found that the speeds of some galaxies are too high to be bound by the gravitational force of the mass of the visible matter. Many galaxies should have escaped from galaxy clusters, unless gravity is provided by invisible matter, called dark matter by Fritz Zwicky in 1933.

In the 1960's, Vera Rubin measured the rotational speeds of galaxies. She found that the gravity of visible matter in a galaxy is far too insufficient to hold the stars and gas in its outer rim, again calling for the need for dark matter. We now know that about 85% of all matter in the universe is dark: it does not interact with light, and is thus transparent and invisible, but it gravitates. Without it, there would be much less structures in the universe today. Popular candidates for dark matter include the particles predicted in supersymmetry and extra-dimensional models, some of which could be produced in LHC experiments.

Dark Energy

Most galaxies seem to move away from us, as indicated by the redshifts of their light. This observation is the same for observers in any other galaxy. This is the expansion of the universe. Since gravity is an attractive force, the expansion speed of the universe should be slowed down gradually by the gravitational attraction between galaxies. However, scientists were surprised to find that the expansion of the universe is instead accelerating, indicating the existence of a previously unknown repulsive force, perhaps resulting from the vacuum itself. This mysterious component of the universe is called dark energy. Many models trying to explain it involve new fields and particles, some of which may be produced in LHC experiments.

Importance of Studying Particle Physics

Particle physics are deeply related to our everyday lives. Out of curiosity, mankind is dedicated to unveiling the mysteries of nature, such as the origin and structure of the universe and why we are here. As the most fundamental science, particle physics is an indispensable part of human civilisation. Additionally, many technologies that are widely used in our society today were developed during pioneering investigations undertaken in the field of particle physics. A growing list of practical applications will be driven by particle physics research in the future.

Hong Kong ATLAS Group



In 2013, the Hong Kong ATLAS group was established by the Chinese University of Hong Kong, the Hong Kong University of Science and Technology and the University of Hong Kong. The group has become a regular member of ATLAS since June 2014 and has grown to a team of around 20 members including faculty members, postdoctoral fellows, research assistants, PhD and MPhil students. Several undergraduate students also joined the group for summer research and final-year projects.

The contribution of the team is very significant as team members have taken on a lot of responsibilities, such as testing electronics for the ATLAS detector, reconstructing collision vertices and muon tracks, and analysing data to discover the properties of the Higgs boson. They have also assisted with the search for new physics discoveries including quantum black holes, new heavy bosons and supersymmetry. A computing centre for ATLAS is also being built in Hong Kong.

Pre-visit Preparation

1. Introduce the working principles of the LHC and related scientific research, so as to help students to better understand the exhibition.
2. Encourage students to research for information about particle physics, such as standard model, relationship between energy and mass, how particles get mass, etc.
3. Guide students to discuss the origin of the universe.

Post-visit Extension Activities

1. Guide students to share what they have learnt from the exhibition, and discuss the importance and future of particle physics.
2. Ask students to search for information about the LHC, then compile a report and present their findings. The information and data can be found in the exhibition, books and the Internet. Research topics can be 'higgs bosons', 'dark matter', 'anti-matter', 'the origin of the universe', etc.

Online Resources

1. <http://scitech.people.com.cn/BIG5/25509/55359/185981/>
2. <http://case.ntu.edu.tw/blog/?p=12555>
3. <http://home.cern/topics/large-hadron-collider>
4. <http://www.stfc.ac.uk/research/particle-physics-and-particle-astronomy/large-hadron-collider/lhc-large-hadron-collider-resource-portal/>