CERN

CERN: The World of Colliding Particles

(Atufa Vora, MacroEdTech)

CERN stands for the European Organization for Nuclear Research. The organization focuses on research into the universe's most fundamental constituent elements. This organization was established in 1954. Its purpose was to unite Europe around science. It is the **largest particle physics laboratory** in the world. Moreover, in addition to having 23 different Member States, it invites scientists from over 100 countries to come and collaborate. It answers big questions about matter and the Big Bang. A great achievement by this organization was the discovery of the **Higgs boson**. It exemplifies the fact that people of different countries can work together for the welfare of humanity. Lastly, the tools developed here serve society. CERN is where the World Wide Web was born, and its sensors are now used in hospitals for medical imaging. The well-known **Large Hadron Collider**, or **LHC**, is nothing but the last link of a detailed chain. Devices like the Proton Synchrotron are much smaller, where the particles originally emanate. Before entering the LHC, they go through a succession of accelerators in which their speed increases with every turn. Not every experiment takes place in LHC. The Antimatter Factory produces and studies antimatter, while other places study nuclear physics and rare isotopes.

Basic Description of LHC

- ## Physical Structure

The Large Hadron Collider is the largest and most powerful particle accelerator in the world. It lies inside a circular tunnel with a circumference of 27 kilometers. The tunnel has been excavated approximately 100 meters underground beneath the border between France and Switzerland. Being deep underground shields the machine from radiation and prevents radiation from escaping.

- ## How It Works

The LHC consists of two pipes enclosed within superconducting magnets. These magnets are kept at temperatures colder than outer space for the guidance of the particle beams.

1. **Acceleration:** the radio-frequency cavities kick the particles and increase their energy as they race around the ring.
2. **Collision:** Two beams run in opposite directions at nearly the speed of light. Powerful magnets squeeze these beams to a tiny size and make them collide at four specific interaction points, where massive detectors are waiting.

Some other beam types

1. **Protons:** For most of the year, the LHC is accelerating beams of protons, which are just the nuclei of hydrogen atoms.
2. **Heavy Ions:** For approximately one month every year, the machine switches over to accelerating heavy ions, usually lead nuclei. This produces much denser and hotter collisions.

Key Experiments and Detectors

The LHC hosts four gigantic main experiments, plus several smaller, specialized ones. Each one is located in an underground cavern at one of the collision points.

General Purpose Giants

- **ATLAS:** This is the largest volume detector ever built for a particle collider. It is 46 meters long and 25 meters high.
- **CMS:** The Compact Muon Solenoid weighs more than ATLAS but is smaller in size. It utilizes a huge solenoid magnet for bending the paths of particles.

The Specialized Major Experiments

- **ALICE:** A Large Ion Collider Experiment, is designed to deal with the messy and complex collisions of heavy lead ions.
- **LHCb:** The Large Hadron Collider beauty experiment looks for certain particles that contain the "beauty" or "bottom" quark.

Smaller and Newer Experiments

- **FASER and SND@LHC:** These are newer additions that catch particles which fly forward along the beamline and that usually pass the big detectors. Both focus on neutrinos, one also on searching for light dark matter.

Purpose and Scientific Objectives

Each of them has played a unique role in explaining the Universe.

- **ATLAS and CMS:** the Discovery Machines

The two experiments are independent but have the same aims; they validate the results against one another.

1. **Higgs Boson:** They were primarily looking for the Higgs boson, which they eventually found in 2012. The properties of this are now being studied in detail.
2. **New Physics:** They also make attempts to locate the extra dimensions and particles that may consist of dark matter-the invisible substance holding galaxies together.

- **ALICE:** Reconstructing the Big Bang

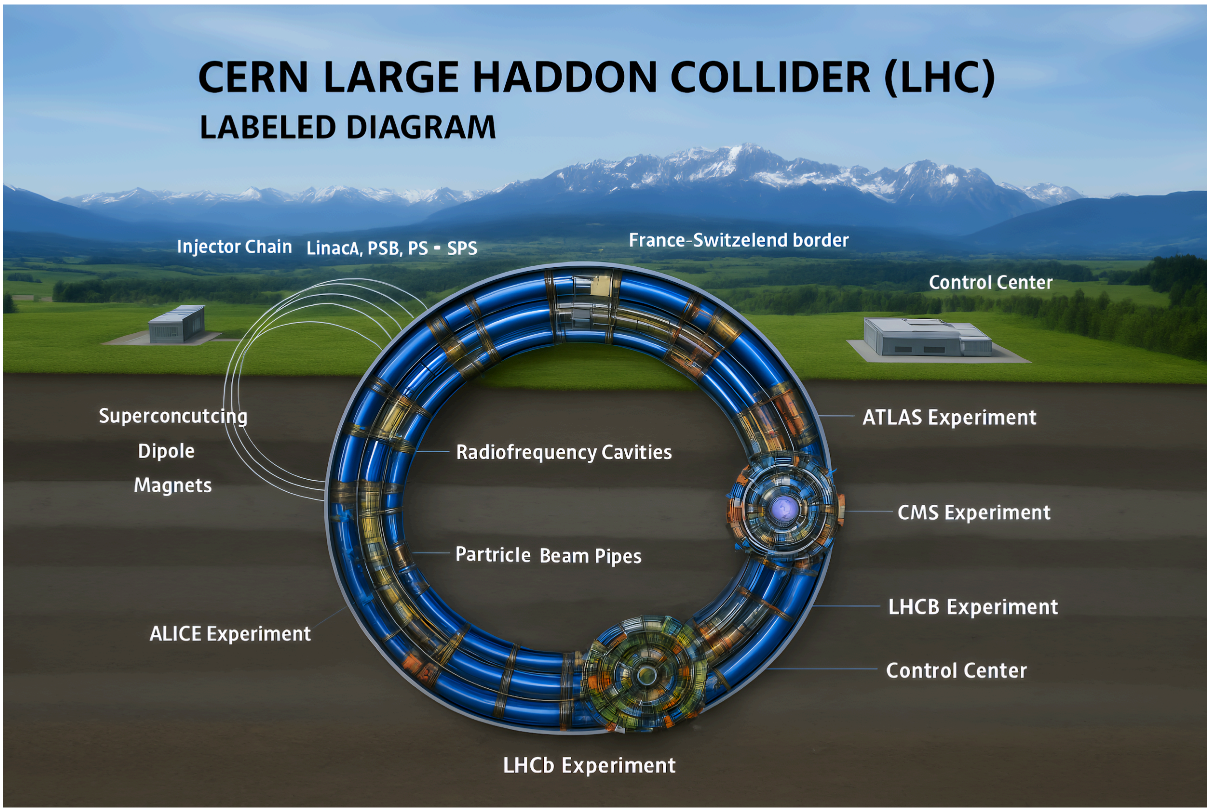
1. **Quark Gluon Plasma:** When lead ions collide, it generates high levels of heat and density. This melts the protons and neutrons into a soup called Quark Gluon Plasma. ALICE studies this fluid to understand how the universe looked in the moments immediately after its birth.

- **LHCb:** Unraveling the Mystery of Antimatter

1. **Matter-Antimatter Asymmetry:** The Big Bang should have created an equal amount of matter and antimatter, which in turn would have annihilated each other instantly. LHCb investigates rare decays of particles containing beauty quarks with the aim of explaining why matter prevailed to form our universe.

- FASER and SND@LHC: the Elusive Particles

1. High Energy Neutrinos - These experiments recently detected the first neutrinos ever produced by a particle collider; they open a new window into studying these ghostly particles at energies never before tested in the lab.



Recent Achievements and New Findings at LHC

Collider Performance and Collision Data

Run 3, the third important run of the Large Hadron Collider (LHC), began in July 2022.

- **Power of the Record:** At 13.6 trillion electronvolts, protons are being struck together. This is the maximum energy that a machine created by humans has ever reached.
- **Volume of Data:** Like a powerful stream of water, the proton beams are very dense. Compared to previous runs, this allows the detectors to gather more collision data. This large amount of data is important for recognizing extremely rare appearances.

Key Scientific Findings

- **Quantum Entanglement in Heavy Particles:** ATLAS and CMS experiments proved that even for heavy fundamental particles, known as top quarks, quantum entanglement occurs. This "spooky action at a distance" refers to how, after separating a long distance, the properties of two particles are mysteriously entwined.
- **Heaviest Antimatter Nucleus:** The ALICE experiment has discovered evidence of the most massive antimatter nucleus yet, which goes by the name antihyperhydrogen 4. This discovery goes a long way in understanding how matter and antimatter differ, as our universe is composed of matter.
- **First Collider Neutrinos:** Small experiments called FASER and SND@LHC made history by detecting neutrinos that were created right inside the particle collisions; previously, these ghostly particles had been seen only from natural sources.
- **Searching for New Forces:** The LHCb experiment measured extremely precisely the rate of rare B meson decays. An indication of a new force or particle that we have not yet discovered would be a small deviation from expectations in these decays.

Recognition and Awards

- **Top Publications:** Their findings and studies are also published on a regular basis on top science journals like Nature and Science.
- **International Honors:** These associations have been honored with major prizes, including the European Physics Society High Energy Physics Prize, for their important contributions to knowledge of the fundamental nature of particles, including the Higgs particle.

Current Research and Future Plans

- **Now (Run 3):** The LHC operates at its record energy of 13.6 TeV in order to accumulate as much data as possible. The aim of this run would be to make precise measurements of phenomena related to dark matter and new physics.
- **Near-Future (HL LHC) Collider:** The facility will be upgraded from 2026 until 2030 to turn it into a High Luminosity LHC. This upgrade will generally result in a ten-fold increase in the rate of collision, enabling scientists to observe even rarer phenomena.
- **Long Term (FCC)**: The plan being proposed for a potential new generation of particle physics from CERN involves a "Future Circular Collider" (FCC) which would be 90 to 100 kilometers in circumference. The operation would begin as an electron collider for high resolution, followed by a 100 TeV proton collider searching for physics beyond that of the current LHC.

Why Studying Fundamental Particles Matters

- **Understanding everything:** The study of basic constituents obtains the fundamental laws of nature and also gives the story of the origin of our entire universe.
- **Technology Advance:** This research is the strong driver of new technology, famously giving the world the World Wide Web. It also leads to advances in medical scanners, computing, and magnets.
- **Global Unity:** CERN brings together thousands of scientists from rival nations to work in harmony, literally pushing the boundaries of human knowledge for the benefit of all.

Challenges and Criticisms

- **Cost and Complexity:** experiments are extremely expensive and challenging. An upgrade of the LHC or an FCC would be extremely costly and pose enormous engineering challenges. So, there is scientific uncertainty. To be sure, there could be diminishing returns. Even with very advanced new computers, there might be mere verification of existing theories and no assurance that there will be a finding of “new physics” things like dark matter particles.
- **Social Questions:** The question being raised here is whether it is worth spending so much money and so much energy on these large science projects when there are so many problems waiting to be tackled. We have a challenge here when it comes to communicating effectively.

Conclusion

CERN's most monumental achievement to date is the discovery of the Higgs boson, which completed the Standard Model of particle physics and provided the key to why particles have mass. But its vitality remains because this finding opened up new questions about dark matter, antimatter, and supersymmetry. This Run 3 that is ongoing, and the future High Luminosity LHC (HL LHC) upgrade starting post 2026, are crucial in making precise measurements of the Higgs and searching for new physics signs that could break the Standard Model. The proposed Future Circular Collider-a much bigger machine-than the LHC would, over the longer term, go on to increase the energy frontier up to 100 TeV and offer the best chance yet of uncovering particles that make up the universe's missing mass and energy. It is a quest for fundamental knowledge that matters to humanity because this kind of curiosity-driven science acts as a powerful driver of progress, driven so far by game-changing technological spin-offs from the technology developed at CERN and major advances in medical imaging and computing.

Recommended Resources

- *CERN Open Data Portal and Open Access Policy*
- *Overview of heavy-ion collision results at LHC (arXiv)*
- *Higgs boson properties from CMS (arXiv)*
- *ALICE experiment summary*
- *FASER experiment*