The Particle Physics Baby Book - *Explained !*

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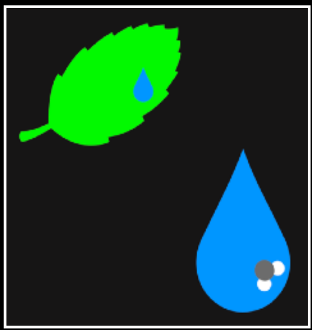
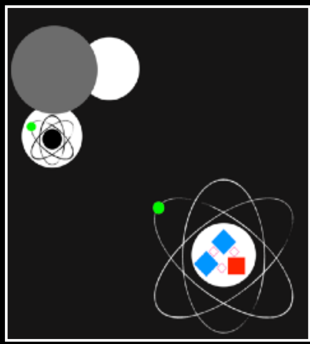


Particle physics is the study of what the Universe is made of. Take a **leaf** for example. If we look a little closer, we can see that it is made mostly of **water**... but what happens if we zoom in further?

Water is a liquid made of **molecules of H_2O.** Molecules are groups of **atoms.** In the case of water, there are two Hydrogen atoms, and one Oxygen atom. **Atoms** are made of even smaller things: **quarks** and **gluons** in a nucleus, orbited by **electron(s)**.



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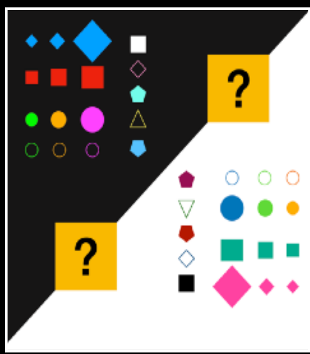
Quarks, gluons and **electron(s)** are part of the **Standard Model,** our best guess so far of what the building blocks of the Universe are. The Standard Model contains the **quarks**, the **charged leptons** and their **neutrinos.** The forces which connect them are carried by other particles: **bosons**.

Could there be ***more*** particles than the ones we know about? **We suspect there are!** We are trying to find them. For example, in a theory called **Supersymmetry**, each Standard Model particle has a mirror twin.



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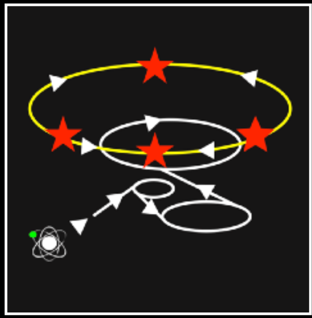
CERN is one of the places where we look for **new particles.** It's on the border between France and Switzerland. It is one of the biggest laboratories in the world! Thousands of scientists from all over the planet work together to understand the universe.

Welcome to CERN's accelerator complex! **Atoms** are accelerated by the Large Hadron Collider, to nearly at the speed of light. Then they are **smashed together** so we can study the particles which are produced.



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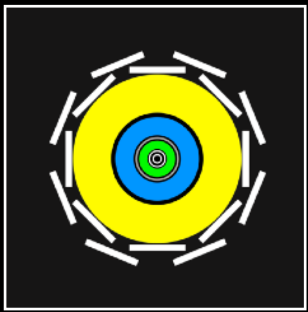
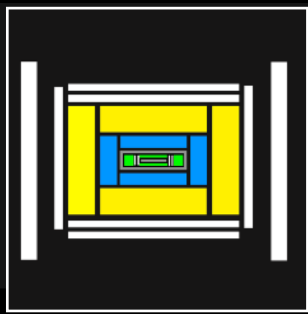


At the collision points, we use huge detectors (like enormous 3D cameras) to look for particles. These are cross-sections of the **ATLAS detector**, along its width and length. From the centre, the **tracking detectors** record trajectories of charged particles; the **solenoid magnet** bends the trajectories of particles so we can estimate their momentum; the **electromagnetic calorimeter** picks up electron and photon deposits; the **hadronic calorimeter** measures activity from particles made of quarks and gluons; and the **muon spectrometer** tells us where muons passed.



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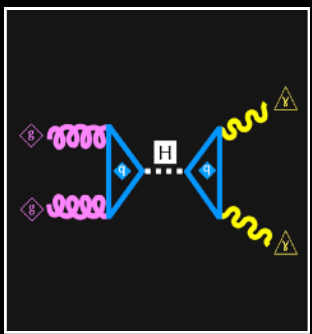
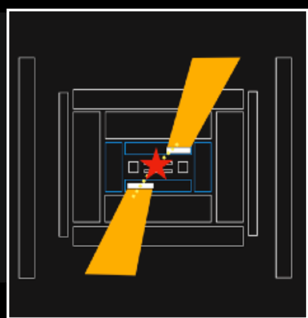


This is a Feynman diagram. It shows how an interaction between particles takes place when we smash together atomic nuclei in the Large Hadron Collider. In this example, two **gluons** fuse via a **quark** into a **Higgs boson**, which decays through **quarks** back into **photons**. In the detector, the **collision** happens right in the middle. We measure the **photons** from **Higgs boson** decays as **energy** in the **electromagnetic calorimeter.** We can reconstruct the mass of the **Higgs boson** by measuring the energy of the two photons and the angle between them.



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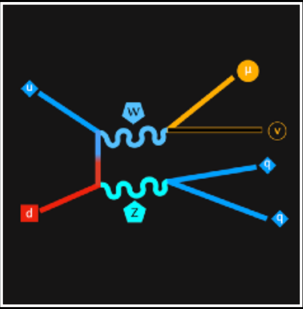
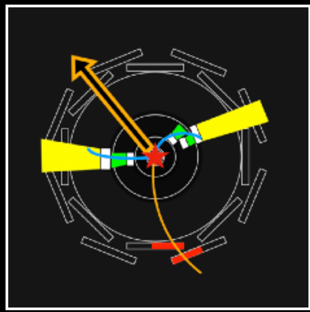


Quarks from the collided nuclei can interact to emit **bosons**, one of which decays to more **quarks**, and the other to a **muon** and a **muon neutrino**. In the detector, the **quarks** form **jets** in the calorimeters. **Muons** are picked up as **hits** in the **muon spectrometer.** The **neutrino** flies straight through the detector: we infer it was there by the amount of missing energy!



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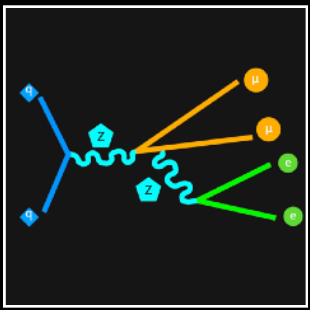
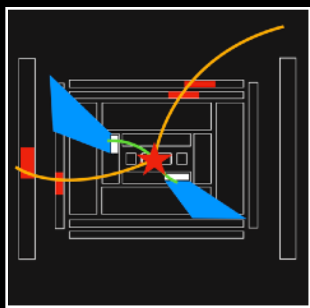


A pair of **quarks** annihilate into a **Z boson**, which then decays into a **pair of muons**, and a pair of **electrons**. In the detector, the **electrons** leave tracks and **energy** in the calorimeter. The **muons** are picked up as **hits** in the muon spectrometer. Electrons and muons are charged particles, so their trajectories are **curved** by the magnetic field inside the detector.



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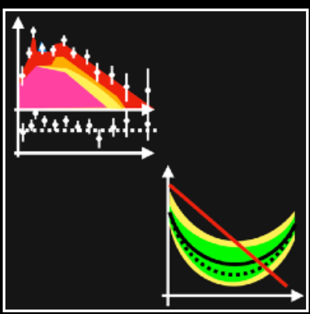

We use our detectors to measure *how often* reactions happen, and compare the **data** to **predictions.** We use our observations to place **limits** on how often new particles could be produced without us having **seen them**. That way we know which new particles we can rule out!

One day we might have an **even bigger collider.** It may be 100 km long, and could go under Lake Geneva. It will take decades to design and build. Maybe ***you*** will become a scientist and use it to find new particles yourself, when you grow up?

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