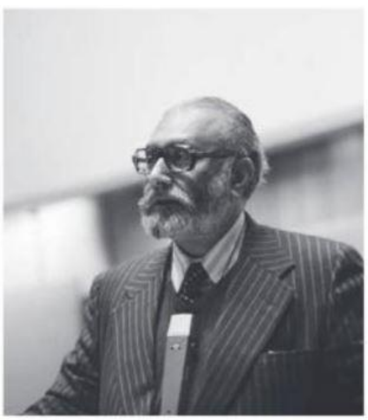
The Standard Model

A catch-all name for quite a success! This nearly 40-year-old theory which describes fundamental particles and their interactions has yet to be challenged. But that hasn't stopped physicists from relentlessly searching for its flaws…



Credit: CERN

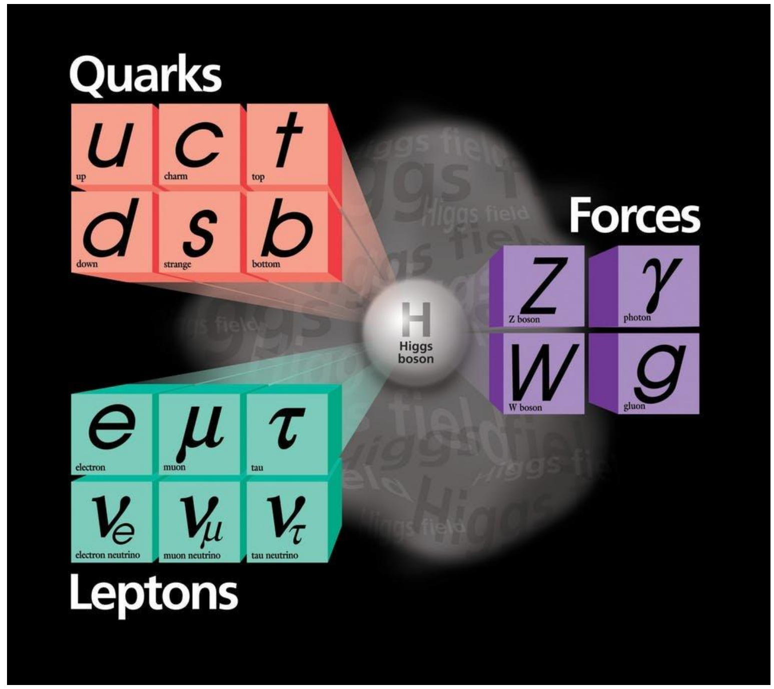
The three winners of the 1979 Nobel Prize in Physics

Abdus Salam, Sheldon Glashow and Steven Weinberg (left to right) were awarded the 1979 Nobel Prize in Physics for their contributions to the theory of electroweak unification, one of the cornerstones of the Standard Model of particle physics. Other Nobel Prizes (in particular, 1999, 2004, 2008 and 2013) have also awarded key theoretical achievements associated with the Standard Model.

Particle physics developed throughout the 20th century by exploring matter in ever greater depth. The process culminated in the 1960s and 1970s with the development of a theory, the Standard Model, which describes the phenomena observed in the most powerful accelerators with unequalled precision, even now. This involved sorting out the hundreds of particles observed – which ones are elementary? – understanding the relations between them and why some processes occur while others seem impossible. Such construction required new mathematical tools, the only ones capable of accurately describing reality – even though this success cannot be fully explained.

The Standard Model comprises twelve fundamental particles called fermions, which can be presented in a table similar to the periodic classification of chemical elements. Each column, or family, consists of four particles. The first group includes the stable particles that make up ordinary matter: the electron, its associated neutrino, and up and down quarks, which form protons and neutrons. All three families have the same structure. In each line, particles share common properties and are ordered by ascending mass.

The particle charges quantify their sensitivity to the three fundamental interactions – electromagnetic, weak and strong interactions – that govern the world of the infinitely small. These forces are conveyed by other carrier particles called bosons. There are also twelve bosons and all have been observed in detectors, either directly or indirectly. The best known is the photon, the constituent of light, which relates to the electromagnetic interaction.



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The Higgs boson at the core of the Standard Model

The Higgs boson is the final piece of the Standard Model puzzle. Its discovery at the LHC was a remarkable confirmation of the model's validity for describing the fundamental constituents of matter and their interactions.

One of the greatest achievements of the Standard Model is the unification of electromagnetic and weak interactions. While these forces seem very different on our scale, they actually stem from a single interaction, known as the electroweak interaction, and their connection, which can be observed experimentally, is visible at high energy levels. The puzzle's final piece is the Higgs boson, evidence of an essential mechanism in the Standard Model: the particle confers mass on all fundamental particles, explaining why W and Z electroweak bosons are massive, unlike the photon. The Higgs boson was discovered in 2012 at the LHC, CERN's large proton-proton collider.

Today the Standard Model has almost become a victim of its own success: even though it is not the 'ultimate theory' of which physicists dream – it does not describe all the phenomena encountered in the Universe, it ignores gravitation, and its equations give absurd results at very high energies – it has brilliantly passed experimental tests for the past three decades. All particle physicists expect the Standard Model to fail at some point, though they don't know yet where exactly it will start to break. Bets are on!

Translated from 'Le Modèle Standard',* Passeport pour les deux infinis, *IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG