deconstruction: standard model discoveries

Sixteen elementary types of particles form the basis for the theoretical framework known as the Standard Model of fundamental particles and forces. J.J. Thomson discovered the electron in 1897, while scientists at Fermilab saw the first direct interaction of a tau neutrino with matter less than 10 years ago.

This graphic names the 16 particle types and shows when and where they were discovered. These particles also exist in the form of antimatter particles, with the same mass and the opposite electric charge. Together, they account for about 300 subatomic particles observed in experiments so far.

The Standard Model also predicts the Higgs boson, which still eludes experimental detection. Experiments at Fermilab and CERN could see the first signals for this particle in the next couple of years. Other fundamental particles must exist, too. The Standard Model does not account for dark matter, which appears to make up 83 percent of all matter in the universe.

1968: SLAC u **up quark**	1974: Brookhaven & SLAC c **charm quark**	1995: Fermilab t **top quark**	1979: DESY g **gluon**
1968: SLAC d **down quark**	1947: Manchester University s **strange quark**	1977: Fermilab b **bottom quark**	1923: Washington University* γ **photon**
1956: Savannah River Plant ν_e **electron neutrino**	1962: Brookhaven ν_μ **muon neutrino**	2000: Fermilab ν_τ **tau neutrino**	1983: CERN W ***W* boson**
1897: Cavendish Laboratory e **electron**	1937 : Caltech and Harvard μ **muon**	1976: SLAC τ **tau**	1983: CERN Z ***Z* boson**

*Scientists suspected for several hundred years that light consists of particles. Many experiments and theoretical explanations have led to the discovery of the photon, which explains both wave and particle properties of light.

The 1950s saw a proliferation of particle discoveries, thanks to the advent of accelerator-based experiments. By 1960, more than 100 particles were known and physicists began to find patterns. Slowly the Standard Model emerged. It has brought order to the particle zoo and explains a steadily increasing number of subatomic phenomena.

Here is a brief summary of 15 **Nobel Prize-winning discoveries** closely connected to the development of the Standard Model, beginning with the "particle explosion" in the 1950s. For more information, visit nobelprize.org. **Text: David Harris and Kurt Riesselmann**

u d s

Nobel work: discovering a large number of particles, achieved through the development of new detection and analysis tools
Laureate: Luis Alvarez
Discovery made: 1959–1964
Nobel awarded: 1968

u d s

Nobel work: classifying the experimentally observed particle zoo by introducing the concepts of strangeness and quarks
Laureate: Murray Gell-Mann
Discovery made: 1953, 1961, 1964
Nobel awarded: 1969

u d

Nobel work: finding the first evidence that protons and neutrons are made of smaller building blocks: quarks
Laureates: Jerome Friedman, Henry Kendall, and Richard Taylor
Discovery made: 1968
Nobel awarded: 1990

s

Nobel work: predicting that the weak nuclear force violates parity, or mirror symmetry, which leads to experimental signatures in beta decay as well as decay of strange particles
Laureates: Tsung-Dao Lee and Chen Ning Yang
Discovery made: 1956
Nobel awarded: 1957

s

Nobel work: discovering that neutral *K* mesons, which contain a strange quark, violate the fundamental matter-antimatter symmetry known as CP
Laureates: James Cronin and Val Fitch
Discovery made: 1964
Nobel awarded: 1980

c

Nobel work: pioneering work in the discovery of the charm quark, the fourth quark observed in experiments
Laureates: Burton Richter and Samuel Ting
Discovery made: 1974
Nobel awarded: 1976

t b

Nobel work: predicting the bottom and top quarks to explain the symmetry-violating behavior of particles containing a strange quark
Laureates: Makoto Kobayashi and Toshihide Maskawa (sharing the prize with Yoichiro Nambu)
Discovery made: 1973
Nobel awarded: 2008

ν_e

Nobel work: detecting the first neutrino
Laureate: Frederick Reines (sharing the prize with Martin Perl)
Discovery made: 1956
Nobel awarded: 1995

ν_e

Nobel work: detecting cosmic neutrinos, produced by the sun and by supernova explosions, thus starting the field of neutrino astronomy
Laureates: Raymond Davis and Masatoshi Koshiba (sharing the prize with Riccardo Giacconi)
Discovery made: 1980s
Nobel awarded: 2002

ν_μ

Nobel work: showing that there are at least two types of neutrinos, thereby discovering the muon neutrino
Laureates: Leon Lederman, Melvin Schwartz, and Jack Steinberger
Discovery made: 1962
Nobel awarded: 1988

τ

Nobel work: discovering the tau lepton, the first observation of a particle that belongs to the third generation of elementary particles
Laureate: Martin Perl (sharing the prize with Frederick Reines)
Discovery made: 1976
Nobel awarded: 1995

g

Nobel work: discovering that as two quarks move away from each other they remain tightly bound together due to the strong nuclear force, mediated by the exchange of gluons.
Laureates: David Gross, David Politzer, and Frank Wilczek
Discovery made: 1973
Nobel awarded: 2004

γ W Z

Nobel for: developing a unified electroweak theory that explains both the electromagnetic force (transmitted by photons) and the weak force (transmitted by *W* and *Z* bosons)
Laureates: Sheldon Lee Glashow, Abdus Salam, and Steven Weinberg
Discovery made: 1960s
Nobel awarded: 1979

W Z

Nobel work: placing particle physics theory on a firmer mathematical foundation, elucidating the quantum structure of the electroweak theory
Laureates: Gerardus 't Hooft and Martinus Veltman
Discovery made: 1971
Nobel awarded: 1999

W Z

Nobel work: making contributions to the project that led to the first direct observation of the *W* and *Z* bosons
Laureates: Carlo Rubbia and Simon van der Meer
Discovery made: 1983
Nobel awarded: 1984