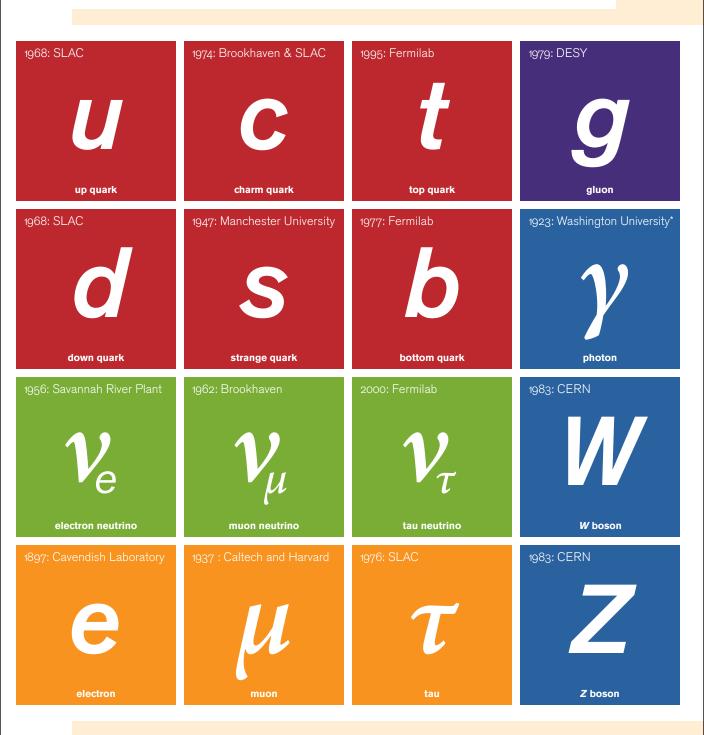
## deconstruction: standard model discoveries

**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.



<sup>\*</sup>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





Nobel awarded: 1968

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 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



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



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



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



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





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



Nobel work: detecting the first

Laureate: Frederick Reines (sharing the prize with Martin Perl)

Discovery made: 1956 Nobel awarded: 1995



**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



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



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



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





Nobel awarded: 1979

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 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



Nobel work: making contributions to the project that led to the first direct observation of the W and

Laureates: Carlo Rubbia and Simon van der Meer Discovery made: 1983 Nobel awarded: 1984