1914, James Chadwick

Neutron → Proton

Neutron

Energy is lost!
What to do?
A new particle so elusive that nobody can detect it!

Enrico Fermi named it the *neutrino* — the “little neutral one.”
1930-1935: The Search for the Neutrino
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No neutrinos found.
1935–1940: The Search for the Neutrino
1935–1940: The Search for the Neutrino

No neutrinos found!
1940-1945: The Search for the Neutrino
1940-1945: The Search for the Neutrino

Still no neutrinos found!!
1945-1950: The Search for the Neutrino
1945–1950: The Search for the Neutrino

Where are those neutrinos??
1950–1955: The Search for the Neutrino
1950–1955: The Search for the Neutrino

Where are those XXXXXX neutrinos??!!!
June 14, 1956
June 14, 1956

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- The conservation of energy wins a battle.
- In 1995, Frederick Reines is awarded the Nobel Prize in Physics for his discovery.
- Clyde Cowan is no longer alive to receive the prize.
Three Kinds of Neutrinos

★ In 1956, Cowan and Reines detected the first neutrino — what we now call an electron neutrino.

★ In 1962, Leon Lederman, Melvin Schwartz, and Jack Steinberger discovered a second type of neutrino — now called the muon neutrino. It is different because it reacts differently:

\[ \bar{\nu}_e + \text{proton} \rightarrow \text{neutron} + \text{positron} \]

\[ \bar{\nu}_\mu + \text{proton} \rightarrow \text{neutron} + \text{anti-muon} \, . \]

★ In 2000, the DONUT collaboration at Fermilab (Direct Observation of the Nu Tau) detected the third type, the tau neutrino (which was by then expected):

\[ \bar{\nu}_\tau + \text{proton} \rightarrow \text{neutron} + \text{anti-tau} \, . \]
The Solar Neutrino Problem

★ The nuclear reactions in the Sun produce neutrinos, and solar theorists claim to be able to calculate the rate.

★ In particular, John Bahcall, in the 1960s, made very careful calculations of the solar neutrino production rate, with the hope of comparing with experiment.
Raymond Davis, Jr., in the late 1960s, constructed an experiment to measure solar neutrinos. He took over the Homestake Gold Mine in Lead, South Dakota, and constructed a 380 meter$^3$ tank of dry-cleaning fluid at a depth of almost a mile.

Solar neutrinos would interact with the chlorine in the tank, producing radioactive atoms of argon, which could be counted.
★ Result: **Too few neutrinos!**

★ Davis detected only about a third of the neutrinos that Bahcall had predicted.

★ For 30 years this discrepancy persisted, and was unresolved.
Solar Neutrino Problem Solved: Neutrino Oscillations

In the 70s and 80s, Mikheyev, Smirnov, and Wolfenstein proposed that maybe the problem could be solved if neutrinos had a small mass. In the strange world of quantum theory, this would mean that one type of neutrino could “oscillate” into another.
The Sun produces electron neutrinos and the Homestake experiment could detect only electron neutrinos. So if the neutrinos oscillated into the other types, they would be missed.

In 2001, the Sudbury Neutrino Observatory was able to detect all three types of solar neutrinos. They found that the total number agreed with John Bahcall’s predictions, but only about 1/3 were electron neutrinos.
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