CERN Reports First Vector Boson Evidence

Six proton-antiproton collision events fit all the requirements for the charged intermediate vector bosons ($W^{\pm}$); the neutral Z^0 is still to come

The most sought after elementary particles in high energy physics may have been sighted at the European Laboratory for Particle Physics (CERN). At a physics workshop in Rome on 13 January and before a packed CERN seminar on 20 January, Carlo Rubbia, leader of one of the two international collaborations looking for the intermediate vector bosons, reported six events from a 2-month run last fall that have all the characteristics required of the two electrically charged vector bosons, the W^+ and the W^-. The experiments were done at CERN's 540-billion-electron-volt-(GeV)-proton-antiproton colliding-beam storage ring, which was created largely for finding these particles (*Science*, 21 May 1982, p. 836, and 10 July 1981, p. 191). In a 21 January seminar, the second group, headed by Pierre Darriulat of CERN, announced it has four candidate events consistent with W's but is making no claims pending further analysis. No evidence for the third of the three predicted bosons, the neutral Z^0, has surfaced yet.

In their carefully crafted announcements, physicists are seldom so blunt as to say they have found a new particle. Instead, they note that the characteristics of the high-energy elementary particle collisions observed match those predicted for the production and decay of the particle in question. This is indeed what Rubbia's UA-1 group, a collaboration of more than 100 mainly European physicists, has done in a paper already submitted to *Physics Letters*. However, in a telephone interview, Rubbia told *Science*, "It's all done; it's all over."

It is difficult to overestimate the importance of the intermediate vector bosons in the thinking of today's high energy physicists. The theories developed for all three of the forces that play a role in elementary particle interactions are of a particular type called gauge theories. The similarities in the structures of the gauge theories are strong enough to have compelled theorists to devise so-called grand unified theories that enfold all three forces into one mathematical framework. Vector bosons (also called gauge particles) are the entities that carry forces between the most fundamental of particles, the quarks and leptons.

The intermediate vector bosons, hypothesized to carry the weak force, are important in two ways. Unlike photons, which transmit the electromagnetic force, and gluons, which do the same for the strong nuclear force, these three particles have mass. In fact, the masses are so large that no accelerator until CERN's proton-antiproton collider has been energetic enough to produce them. And the means by which the vector bosons obtain their mass is also the key to the unification process. For theorists to be sure they are on the right track, all three particles must be found and must have the detailed properties predicted by the theory that unites the electromagnetic and weak forces. This is sometimes called the Weinberg-Salam-Glashow model after Steven Weinberg of the University of Texas, Abdus Salam of Imperial College, London, and Sheldon Glashow of Harvard University, who received the 1979 Nobel Prize in Physics for their roles in developing it.

Quarks have several properties that distinguish the numerous varieties, but they all have an electrical charge of either $+2/3$ or $-1/3$. Protons comprise three quarks, two with charge $+2/3$ and one with charge $-1/3$. Antiprotons contain antiquarks with the opposite charges. The simplest way to make W vector bosons in a proton-antiproton collision is by way of quark-antiquark interactions. The annihilation of a quark with charge $+2/3$ and an antiquark with charge $-1/3$ produces a W^+, for example. The W particles can decay in several ways, but a particularly distinctive signature is the production of a single electron (for the W^-) or positron (for the W^+) and a neutrino that fly away from the decayed particle at high speed in opposite directions. The six events seen by the UA-1 group are of this type.

Rubbia summarized for *Science* the evidence that points the six events toward intermediate vector bosons. During the experimental run in October and November, roughly 1 billion proton-antiproton collisions were registered. High-speed electronic and computer "triggers" pared this number down to a final group of 100,000. From these, physicists found six with electrons having very high velocities perpendicular (transverse) to the direction of the colliding proton and antiproton beams, which is one sign of quark-antiquark interactions. Independently, the physicists found six events in which a large fraction of the transverse energy released in the collision was not recorded. This missing energy is due to neutrinos, which particle detectors cannot see. It turned out that the six events of each type were the same ones—giving the distinctive signature of W particles.

Furthermore, statistical fits to the spectrum of energies of the electrons and neutrinos allow physicists to estimate the mass of the decayed particle. One such test showed that the particle mass must be at least 74 GeV (with, in statistics jargon, a 90 percent confidence level). A second test yielded a mass of 81 ± 5 GeV. The most recent calculations of the W particle mass from the Weinberg-Salam-Glashow model give 82.1 ± 2.4 GeV.

Finally, physicists can estimate how often W particles should be produced in proton-antiproton collisions by means of theoretically calculated cross sections and statistical (Monte Carlo) simulations of collision events. The UA-1 group did this and found that they should have observed 4.9 events of a particular geometry and 0.8 events of another. They actually found 5 of the first type and 1 of the second.

It is not true, of course, that "It's all over." Leon Lederman, the director of the Fermi National Accelerator Laboratory, points out that with only six events it is still not excluded that bad luck could cause certain statistically unlikely events to mimic W's. For confirmation, there should be as many events in which muons and neutrinos are the W decay products as there are events in which electrons and neutrinos are the decay products. The same holds for the observation of tau leptons and neutrinos. Rubbia says the group already has one good muon candidate event. Lastly, there should be three times as many events in which the W's decay into hadrons (particles made of quarks) rather than leptons. The hadrons would be in the form of two tightly clustered "jets" of several pions, protons, and strange particles that fly off in opposite directions.

All of these questions, together with the essential observation of the Z^0, should be answered in future experimental runs. The next one starts in April and could generate ten times as many particles as are already recorded, thereby providing more convincing "statistics."

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