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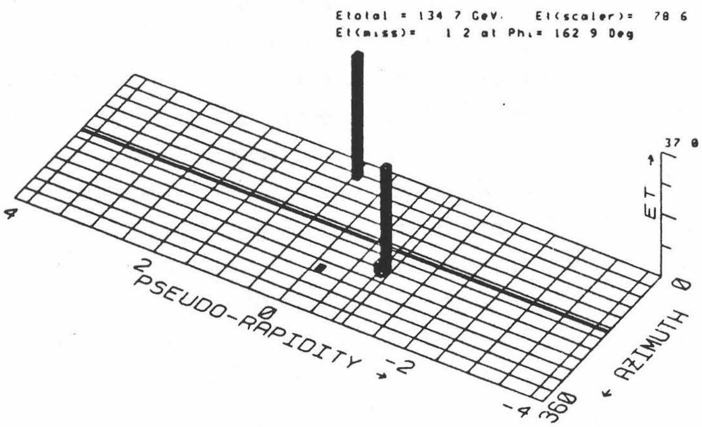
CDF Presents Precise Measurement of Z^0 Mass

The Collider Detector at Fermilab (CDF) collaboration announced today that they had analyzed the largest sample of Z^0's ever seen and had succeeded in obtaining the most precise measurement of the mass of this once exotic particle. CDF is an international collaboration of institutions from the U.S., Italy, and Japan. (Fermilab is operated for the U.S. Department of Energy by Universities Research Association, Inc.)



A CDF "Lego" plot showing an electron-positron pair resulting from the decay of a Z^0.

In a paper sent to the *Physical Review Letters*, CDF reported the new mass value as 90.9 GeV with an uncertainty of plus or minus 0.35 GeV, six times more precise than any previous measurement.

The Z^0 is a subnuclear particle of extraordinary mass which can be produced in collisions of very-high-energy particles and which lives for about one tenth of a trillionth of a trillionth of a second (10^{-25} sec).

Why is the Z-Mass Important?

Physicists recognize four forces of nature which regulate the interactions between particles. The weak force induces reactions which most commonly appear as radioactivity, i.e., the spontaneous disintegration of substances such as Cobalt 60 or Strontium 90. These effects are manifestations of a much deeper set of processes between fundamental particles, quarks and leptons. The carriers of the weak force are three massive particles: W^+, W^-, and Z^0. The carriers of the electromagnetic force which holds atoms together and defines the properties of electrical and magnetic fields is the photon. In the 1970s, these two forces were unified by a theory developed by Abdus Salam, Steven Weinberg, and Sheldon Glashow (Nobel Prize, 1979). That these apparently dissimilar phenomena were intrinsically one (electroweak) force was hidden from physicists for decades, in no small part because the photon has zero mass and W's and Z's are very massive. The issue then was: What creates the mass of the W and Z? The now accepted answer is the postulated existence of a new field, called the Higgs field - a rather mysterious, all-pervasive field that modifies the purity of the physicist's vacuum and gives mass to particles somewhat like a heavy oil that would tend to slow down runners and make them appear sluggish and massive.

The exact nature of the Higgs effect is one of the outstanding puzzles in particle physics and is one of the drives for the SSC machine - which is designed to confront the Higgs directly. However, in the meantime, precise study of the masses of the W and Z can illuminate subtle influences of the Higgs field. The Fermilab Z measurement is the first important step in this process. It is expected that later this year, the CERN machine (LEP) and the Stanford Linear Accelerator Center (SLAC) machine will produce even greater numbers of Z's than are now available. However, neither of these machines can produce W's. The CDF collaboration has collected a sample of 5000 W's and is in the process of making a precise determination of the W's mass. The difference between the W mass and the Z mass will provide an important test of the model of the electroweak force. The other major unknown in the model is the mass of the yet undiscovered sixth quark, the top quark. The CDF collaboration is currently searching for this elusive particle in its data sample.

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More About the Z

The Z^0 is the glamour particle of the 1980s. Predicted to exist theoretically in the 1960s as an essential ingredient of the physicist's weak force, it was discovered at the European accelerator laboratory CERN in 1984, winning a Nobel Prize for now CERN Director Carlo Rubbia. The CERN accelerator, making use of a novel technique, generated head-on collisions of protons and antiprotons in the CERN proton synchrotron. Operating at a total energy of near 600 GeV, the CERN scientists, over the period 1982-1987, measured about 50 cases of the production and decay of Z^0 particles. The mass of the Z^0 was predicted by the theory of weak interactions to be about 90 GeV or about 100 times the mass of the proton. It is this extraordinary mass which made the Z^0 hard to produce but which, at the same time, makes the Z^0 an object of great interest. So great is this interest that the CERN laboratory has invested over one billion dollars in an accelerator designed to produce Z^0's in collisions of electrons and positrons so that they can study the large number of decay products which emerge when it disintegrates. At CERN, four major detectors, each constructed by a consortium of over 300 physicists, are poised to begin their research at the new LEP (Large Electron Positron) Collider built on the French-Swiss border near Geneva, Switzerland.

In the U.S., SLAC has also invested heavily in a "Z^0 Factory" to study the disintegration properties of this important particle. SLAC began observing Z^0's in April.

In the Fermilab accelerator, protons and antiprotons circulate in opposite directions in the vacuum chamber of Fermilab's TEVATRON. The TEVATRON's collider mode requires the production, collection, and storage of an intense source of antimatter: specifically antiprotons. Although this technique was pioneered at CERN, the Fermilab Antiproton Source feeding into the TEVATRON is the most powerful accelerator, equalling in intensity and exceeding the energy of the recently upgraded and modernized CERN ring. Antiprotons are produced by the collisions of 120-GeV protons with a dense target. They are transported in a high-vacuum beam tube to the antiproton collection and storage facility (two concentric rings of magnets with a circumference of 475 meters) where, after some 6-12 hours, some tens of billions of antiprotons are accumulated and can be transported back to the TEVATRON and accelerated, together with counter-rotating protons, to the peak energy of 900 GeV, about three times higher than the CERN proton-antiproton collider. In the subsequently organized head-on collisions, a total of 1800 GeV is expended and it is in this microscopic cauldron that Z^0's are produced. In a run which ended on June 1 of this year, some 500 Z^0's were detected. This is over 10 times the number of Z^0's previously detected and reported.

These Z^0's were observed by the CDF particle detector group, an international collaboration of 11 U.S. universities, three national laboratories, and two institutions each in Italy and Japan. The collaboration has about 250 physicists and graduate students, and the co-leaders are Melvyn Shochet of the University of Chicago and Alvin Tollestrup of Fermilab. The Italian team is led by Professor Giorgio Bellettini. The Japanese team is led by Dr. Kunitaka Kondo. CDF's online computers examine each of the 50,000 collisions per second and pass interesting collisions on for further analysis. This analysis and selection process continues until about one per second of the most interesting events are stored on high-density magnetic tape. In the 11 months of running, about 1 trillion collisions were examined and about 10 million events were stored on tape. An event consists of a record of the trajectory of all the particles produced in the head-on collision (there could be as many as 100 particles, all of whose masses are generated out of the energy of the collisions via $E = mc^2$). The Z^0 events emerged from this analysis.

One particular mode of disintegration of the Z^0 is of particular interest to Fermilab physicists; this is when the Z^0 disintegrates into a positive and negative electron or muon. Accurate measurements of the energy and momentum of these particles can yield a precise value for the mass of the Z^0. This is a crucial parameter in the weak force theory since it can be predicted from the mathematical structure of the theory. The CERN measurement, based on relatively less elaborate detectors (two were used at CERN: UA1 and UA2) and on only 50 events, had a margin of error six times larger than that reported today.