The discovery of intermediate bosons

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On January 20, 1983, at the CERN seminar, Professor Carlo Rubbia reported one of the most significant discoveries of twentieth century physics—the discovery of intermediate vector bosons. As is well known, the existence of intermediate bosons W^+, W^-, and Z^0 was predicted by the theory of the electroweak interaction. For their decisive contribution to the creation of this theory, S. Glashow, S. Weinberg, and A. Salam received the Nobel prize in 1979. See their Nobel lectures in Rev. Mod. Phys. **52**, 515–543 (1980), Russian translation in Usp. Fiz. Nauk **132**, 201–254 (1980).

The existence of intermediate bosons—the carriers of the weak interaction—was discussed by theoreticians long ago, beginning with the well known work of Yukawa published in 1935—the very work in which he predicted the existence of the π meson. However, only after creation of a unified theory of electromagnetic and weak interactions did the possibility appear of reliably predicting the properties of these particles and first of all their masses: $m_W \approx 80$ GeV and $m_{Z^0} \approx 90$ GeV. None of the previously existing colliding-beam accelerators had energy sufficient to exceed the production threshold of the W and Z bosons. At the beginning of 1976 C. Rubbia, D. Cline, and McIntyre proposed construction of proton-antiproton colliders based on the two largest proton accelerators, at CERN and at Fermilab. In 1978 the decision was made at CERN to proceed with construction of such a machine.

The first collisions of protons and antiprotons with energies of 270 GeV were observed in the collider in the summer of 1981 (see the article by D. B. Cline, C. Rubbia and S. Van der Meer in Scientific American **246**(3), 48–59 (March 1982), Russian translation in Usp. Fiz. Nauk **139**, 135 (1983)

However, another year and a half was necessary before the luminosity of the collider was raised to the point where it became possible to observe the production and decay of W bosons. The point is that the cross section for production of W bosons is very small in comparison with the cross total cross section for collision of a proton and an antiproton: the few recorded W bosons were obtained from approximately 10^9 collisions.

The experiment at CERN is unique in a number of respects. The striking features include the scale of operation (138 authors, and a detector weighing two thousand metric tons) and the speed of the mathematical processing of the events (about one month). However, the most striking thing is perhaps the harmony in which the efforts of the experimental physicists, accelerator physicists, and theoretical physicists were joined in this discovery. (A brochure on the CERN antiproton project published at CERN begins the history of this project as follows: In 1967 at the Institute of Nuclear Physics at Novosibirsk, USSR, the technique of electron cooling was invented for the purpose of obtaining intense antiproton beams for the physics of colliding proton-antiproton beams at an energy of 25 GeV.)

Considering the importance of the discovery of W bosons, the editors of Uspekhi Fisicheskikh Nauk print below [Usp. Fiz. Nauk **141**, 501–516 (1983)] a translation of the first article in which this discovery is reported (G. Arnison *et al.*, Phys. Lett. **122B**, 103 (1983)). Soon after the publication of this aritcle there appeared an article from another group working on the CERN $p\bar{p}$ collider which recorded observations of four more W bosons (M. Banner *et al.*, Phys. Lett. **122B**, 476 (1983)).

In June 1983 the UA1 group (G. Arnison *et al.*, CERN preprint EP/83–73, Phys. Lett. **126B**, 398 (1983)) reported observation of the first five cases of production and decay of Z bosons: four cases of decay into an e^+e^- pair and one case of decay into a $\mu^+\mu^-$ pair. The mass of the Z boson turned out to be of the order of 95 GeV.

In August 1983 the group UA2 (P. Bagnaia *et al.*, CERN EP/83–112) reported observation of eight more cases of the decay $Z^0 \to e^+e^-$ ($m_Z \approx 92$ GeV). Also in August 1983 the UA1 group (G. Arnison *et al.*, CERN preprint EP/83–111) published the results of analysis of 52 cases of production and decay of $W^\pm$ bosons into $e^-\tilde{\nu}_e$ and $e^+\nu_e$. Both the production cross section and the data on angular distribution of electrons and positrons are in agreement with theoretical predictions.

In the summer of 1983 the maximum luminosity of the CERN $p\bar{p}$ collider exceeded 10^{29} cm^{-2} sec^{-1}.

An extensive program of study of W and Z bosons is planned at the Tevatron $\bar{p}p$ collider at Batavia, where beams of p and $\bar{p}$ with a particle energy in each beam of 1 TeV should collide. At CERN the electron-positron collider LEP is being built especially for production of Z bosons in collisions of electrons and positrons. This machine, which is located in a ring tunnel of length 27 kilometers, should come into operation in 1988. It is possible that the e^+e^- collider which is proposed to be built on the basis of the linear accelerator at Stanford (USA) will come into operation somewhat sooner than this.

In the next ten years it is proposed to begin work on a large proton storage-ring accelerator complex at the Institute of High Energy Physics, Serpukhov, where the energies of the colliding particles will reach 3 TeV.

The discovery of intermediate vector bosons has confirmed the correctness of the basic ideas of the theory of the electroweak interaction. However, this theory can be considered verified in all aspects only after discovery of the so-called Higgs scalar bosons, which have zero spin. In the framework of the contemporary theory, scalar bosons are responsible for the appearance of mass in all elementary particles (intermediate vector bosons, leptons, and quarks). Unfortunately the theory cannot at present uniquely predict what should be the masses of the scalar bosons themselves. Therefore it will be necessry to carry out searches for these particles over a very wide range of energies.

Translated by C. S. Robinson