New Physics, Old Rivalries

Geneva was set to be the center of world attention for exciting new findings in high energy physics—but their competitiors in California had other ideas

LAST WEEK, the theoretical underpinnings of high energy physics got simpler, but the politics got more complicated. Physicists at the Stanford Linear Accelerator Center (SLAC) and at the European Laboratory for Particle Physics (CERN) independently proclaimed that they have solid evidence that there are no more than three "families" of fundamental particles—a vital confirmation of the "standard model" of high energy physics. SLAC and CERN made their announcements just 1 day apart, with each group insisting that its contribution was crucial.

The announcements are the latest installment in a long-running transatlantic race to be the first to detect and study the Z^0 particle. The competition began early in the decade. Stanford gambled that it could produce Z^0s in quantity using a modified version of its old linear accelerator before CERN could finish building LEP, its new electron positron collider. The gamble paid off, but only by a matter of months. Stanford took its bows for the first Z^0 earlier this year (see *Science*, 19 May, p.771).

But when LEP started operating, it produced far more Z^0s than the Stanford machine, and this has permitted CERN scientists to study the particle in more detail. They anticipated moving to center stage last Friday, when they released their findings. But the day before, Stanford scientists announced their latest results—coming to much the same conclusions and forcing CERN to share the limelight. This infuriated physicists working at LEP.

Bickering aside, the clearer picture of how the Z^0 decays provides a crucial part of the puzzle of how matter exists in the universe. The standard model of particle physics says that there are four fundamental forces in nature, each with its own carrier particle. Electromagnetism has the photon; gluons carry the strong nuclear force; the vector bosons—W^+, W^-, and Z^0—carry the weak nuclear force; and the graviton (still to be found) carries gravity. The model also predicts that the quarks and leptons are grouped into "families." Three families are known, each with one pair of quarks—resepectively up and down, charmed and strange, top and bottom—and a matching pair of leptons: the electron and its neutrino, the muon and its neutrino, and the tau and its neutrino. The question is, how many families are there? The standard model itself places no limit.

Enter the Z^0. Because it is the heaviest of the vector bosons, it is the most likely particle to produce particles belonging to a fourth family. But the CERN and SLAC measurements of the rate at which it decays virtually rule out that possibility.

The new CERN measurements, based on a total of more than 11,000 Z^0s, compared with less than 500 Z^0s at Stanford, are nearly three times as accurate as those produced by the Stanford Linear Collider according to Alasdair Smith, a senior CERN scientist. And many more Z^0s are on the way. "LEP was designed as a Z^0 factory," says Carlo Rubbia, director general of CERN, "and it works."

SLAC director Burton Richter is not bothered that SLC produces far fewer Z^0s than LEP. He stresses that his machine was built as "proof of principle," to show that a linear collider will work. "It has indeed proved that," says Richter.

LEP resides in a circular concrete tunnel, nearly 17 miles long, which runs between 160 and 490 feet beneath the ground in the countryside near Geneva. In the accelerator ring, beams of electrons and their antimatter equivalents, positrons, race in opposite directions. At four points around the ring, superconducting magnets force the two beams together, causing the electrons to smash into the positrons. Out of the energy of their annihilation come showers of new particles, which four different detectors—dubbed ALEPH, DELPHI, L3, and OPAL—are poised to measure. Each captures the position and movement of particles as they speed through the detectors. That information is used to reconstruct the event that created the particles. Z^0s themselves are too short-lived to be visible in the detectors.

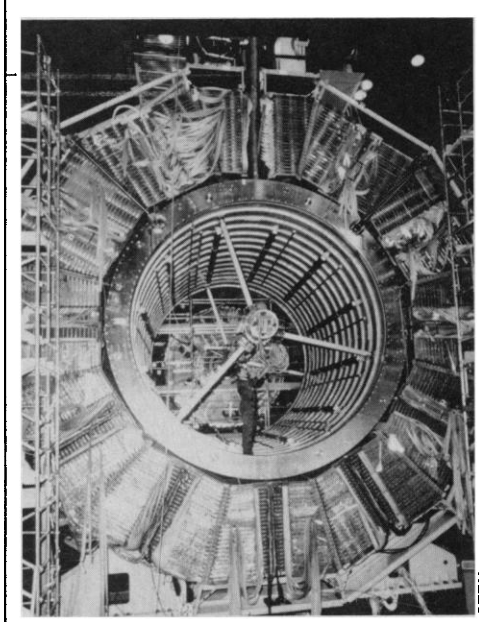
So far, OPAL has detected some 4500 Z^0s, slightly more than ALEPH. L3 has found about half as many and DELTA half as many again.

Nobel laureate Jack Steinberger of Pisa University, who heads the ALEPH team, finds it "absolutely amazing" that any of the teams is "in a position to consider publishing" just 2 months after LEP became operational. Steinberger cites three reasons for this unprecedented speed.

First, all the teams have been planning and developing their equipment since even before LEP was given the go-ahead 8 years ago. They have had time to get things right. Second, the teams are large, averaging about 200 scientists, two or three times the size of teams on previous experiments in high energy physics.

And finally there is the competition between the four detector teams. Each set out, at least initially, to do the same things. "If you're not ready," Steinberger told *Science*, "someone else is." Competition, however, creates an inevitable tension between speed and accuracy. "It's nice to be first," says Smith, who is second in command of the OPAL team, "but on the other hand it's only nice to be first if you're right."

OPAL was indeed first. OPAL is based on tried and tested detector technology and sees Z^0s almost as they happen, whereas the other three have to wait to analyze the data they have gathered. (L3 can take 6 hours to analyze data gathered over a 30-minute peri-


CERN

Catching Z^0s. *ALEPH is one of four detectors around the LEP ring.*

od.) "We actually had our first Z^0 before the machine people announced the beams were colliding," says Smith, with more than a trace of pride. "We knew before they did that the thing worked."

Now that the crucial data on Z^0 are in, what next? In addition to further refining their measurements of the Z^0, the LEP physicists are putting top priority on searching for new and unusual phenomena. And the best strategy for doing that, says Smith, is to "sit on the peak" of the Z^0, producing as many of these particles as they can. The more Z^0s you have—and LEP plans to generate one every 2 seconds when it is really fired up—the more likely you are to see a rare event.

At the top of the most-wanted list is the top quark. Of the six quarks predicted in the three known particle families, only five have so far been seen. The top is missing, and experimentalists and theorists alike would rest easier if they could nail it.

Finding it could be tricky: Richter points out that the latest results from Fermilab in Chicago indicate that the energy of the top quark is between 80 and 85 GeV. Since a collider can produce a top quark only if it also produces an anti-top quark, the total energy needed will be about 165 GeV, beyond LEP's current 100 GeV capability.

And then there is the Higgs boson.

The Higgs boson is perhaps the most perplexing mystery in modern particle physics. No one has ever observed one. No one is even quite sure where to look for one. And yet, says Peter Higgs, the Edinburgh University physicist who first proposed it back in the 1960s, it "saves the mathematical consistency" of the standard model. Without the Higgs boson, or something like it, particles such as the electron would have to have zero mass—which they most certainly do not.

So physicists are almost universally agreed the Higgs is there to be found. The problem is, how? When it comes to the top quark, the searchers at least know where to look, even though no accelerator presently has the capability of producing it. But the Higgs boson could be anywhere.

Nor can anyone predict exactly how the Higgs boson will reveal itself. But this is where the different CERN experiments will come into their own. If the Higgs usually decays into muons or electrons, then L3 stands the best chance of seeing it. If it decays into quarks, one of the others might pick it up first.

Higgs himself does not seem too enthralled by the prospect of his postulate finally becoming a reality. "That would be nice, yes," was all the enthusiasm he would allow himself. ■ JEREMY CHERFAS

Ozone Hits Bottom Again

Atmospheric chemist Susan Solomon had a bet with Joseph Farman, the discoverer of the Antarctic ozone hole, that this year's hole would be a modest one, about like last year's. She lost in a big way. Beyond a free dinner for Cambridge University aeronomist Farman, the outcome means meteorologists have even less idea of what controls the year-to-year fluctuations in the extent of Antarctic ozone depletion than they had hoped. As a result, planning the study of future ozone holes with limited resources will be further complicated.

This fall's observations from Antarctica left no doubt that Farman was the winner. The destruction of ozone that each year eats a "hole" in the stratosphere's ozone layer began in August and by October had created some of the greatest losses and thus one of the deepest holes ever. "It's very hard to find differences between this hole and the 1987 hole," which had held the record as the deepest, according to satellite monitoring by Arlin Krueger of the Goddard Space Flight Center in Greenbelt, Maryland.

Despite the near 50% destruction of ozone over parts of Antarctica this year, the hole shows no sign that it could consume any more ozone. A swirling vortex of winds at the pole confines the hole, keeping its diameter constant from year to year. And ozone losses have been limited to a layer in the lower stratosphere between altitudes of 15 kilometers and 23 kilometers, where the presence of icy clouds catalyzes ozone destruction. However, within these spatial limitations, losses were extreme, thanks to the exceptional cold within the hole this year. The cold created ideal conditions for ozone destruction—lots of ice clouds capable of unleashing ozone-destroying chlorine derived from man-made chlorofluorocarbons.

It was this exceptional cold that Solomon had not counted on. The scientist, who works at the National Oceanic and Atmospheric Administration's Aeronomy Laboratory in Boulder, had been betting on a 1986 study by her and Rolando Garcia of the National Center for Atmospheric Research, also in Boulder. They had refined a reported correlation between the direction of stratospheric winds over the equator and the depth and temperature of the hole. When tropical winds blew from the east, the Antarctic ozone hole was warmer and not so deep; when they blew from the west, it was colder and deeper than usual. Conveniently enough, equatorial winds alternate direction about every 27 months in the reasonably predictable phenomenon called the Quasi-Biennial Oscillation or QBO. So Solomon could extrapolate from the record of past QBOs and predict easterlies, less cold, and thus a shallow hole in 1989.

Just how the equator and pole are connected was a bit mysterious, but there was reason to think that equatorial easterlies are somehow linked to increased stratospheric eddy activity, the winds that tend to stir the atmosphere. Presumably, the more eddy activity, the more heat transported by winds to the Antarctic, the warmer the hole, the fewer ice clouds, and the less ozone destroyed.

Farman believes that the QBO plays a role in the depth of the ozone hole, but he holds that the hole's behavior is more complicated, and thus less predictable, than that. For his 1989 bet, he took a cue from what happened as the 1988 hole drifted off the pole and broke up. Air from the upper stratosphere sank to replace the hole, and that air was most likely unusually rich in chlorine. Given plenty of the required chlorine, his bet that the hole would be deep depended on the less certain appearance of cold temperatures to form enough ice clouds.

Farman got his cold. Eddy activity at lower latitudes was subdued, and less heat got to the Antarctic stratosphere. That part of the QBO hypothesis held up well enough, notes Leslie Lait of Goddard. The problem is that such conditions were expected to prevail under a westerly QBO, but instead it has been in its easterly phase.

That is a strike against the hypothesis that the QBO modulates hole formation, but it hardly negates it. Lait and his colleagues at Goddard recently found the QBO–ozone hole relation to hold 9 out of 10 years. Now it is 9 out of 11, notes Lait, which is still not bad in meteorology. As Solomon observes, "Forecasting stratospheric weather isn't that much easier than forecasting the weather [near the surface]." So all bets are off for next year. ■ RICHARD A. KERR

ADDITIONAL READING

L. Lait, M. Schoeberl, P. Newman, "Quasi-biennial modulation of the Antarctic ozone depletion," *J. Geophys. Res.* **94**, 11559 (1989).