SLAC Feels the Thrill of the Chase

With Z particles now in regular production, Stanford's troubled "Z factory" finally seems to be on the right track

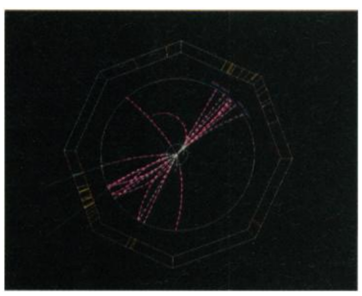
AT 7:32 IN THE MORNING of Tuesday, 11 April, just as the owl shift was coming to an end at the Stanford Linear Accelerator Center (SLAC), a sudden pulse of energy flashed through a 1800-ton cylinder of wire and iron known as the Mark II detector. No one particularly noticed the event—it lasted only about 10^{-25} second—and the computers simply recorded it onto magnetic tape along with thousands of other pulses. No one even had a chance to analyze it until early the following morning, when the data tape was full.

And yet, by the late afternoon of 12 April, word of that infinitesimally brief pulse had sent hundreds of jubilant physicists thronging into the SLAC quadrangle to celebrate with plastic cups of champagne: finally, after half a decade of feverish work and anxiety, SLAC's latest, most ambitious, and most troubled project, the Stanford Linear Collider, had produced a Z particle.

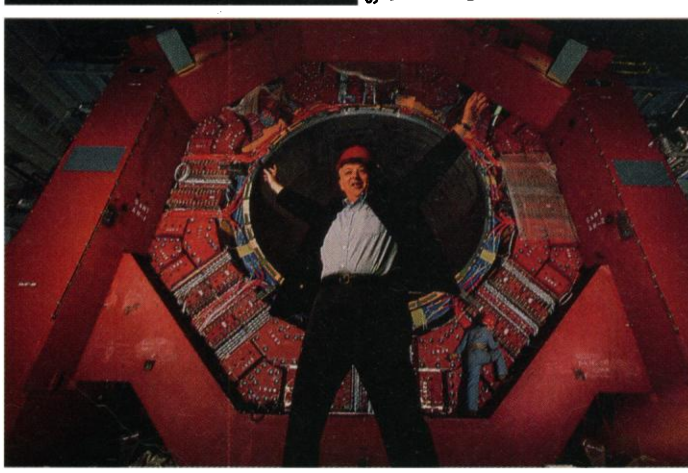
"I'm happy, with relief and joy," declared SLAC's Nobel laureate director Burton Richter, standing on a picnic table and addressing his colleagues like a general amidst his victorious army. "The machine we struggled so hard to make work is starting to perform as it's supposed to."

Relief and joy indeed: that first Z event had come none too soon. Scientifically, the Z was and is the Rosetta particle, the key to clarifying many of the still murky details of particle unification. But for better or for worse it had also become a potent political symbol. At the European Center for Particle Physics (CERN) in Geneva, where the Z had first been observed in 1983, European physicists were steadily moving ahead toward midsummer completion of a rival Z factory known as the Large Electron-Positron project (LEP); a few more months and Stanford's collider might have gone down in the record books as an also-ran, its once commanding lead whittled away by the technical problems that spoiled its inaugural data run last summer and delayed the project for the better part of a year.

Having spent $115 million of the government's money on the promise of building an *American* Z factory, and doing it first, Richter and his team very badly needed that real live Z to redeem their credibility. And now they had gotten it. "This is sort of a recovery from bad times," said Richter, who has been a prime mover of the project since he first conceived of it back in the 1970s, "and I hope the good times now will start." Of course, as Richter has also been reminding his happily exhausted troops ever since, "One leaf does not a laurel make." To make any real advances in science, the Stanford collider team is going to have to produce not just one Z or even a handful of Zs, but thousands of Zs. (As *Science* goes to press, the slowly rising count stands at 16.) And that, in turn, means that the physicists still face a monumental amount of work just to bring the machine up to speed.



SLAC



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The mark of the Z. *(Left) A computer view of Stanford's fifth Z event shows the short-lived particle's decay products: a quark, an antiquark, and a gluon yielding three jets of ordinary particles.* **Richter triumphant.** *(Below) SLAC's director gives the high sign. Behind him looms the Stanford Large Detector.*

There are two things that make this tricky: the nature of the collider itself, and the mix of the laboratory's two cultures. First the collider: it is a kluge, a patched-together prototype with more than a touch of Rube Goldberg in it. "This is not the way you would *begin* to build a machine to do Z physics," says Jonathan Dorfan, one of the leaders of the physicists working with the Mark II detector—not, that is, unless you just happen to have a 50-billion-electron-volt (GeV) linear accelerator lying around the lab. But that is exactly what SLAC does have: the 3-kilometer linear accelerator that gave the laboratory its name and that has been in operation since 1966. The collider was therefore built as an add-on, looping out from the end of the accelerator like the head of an 1-kilometer-wide squash racket.

Conceptually, at least, the operation is straightforward. The accelerator simply fires alternating bundles of electrons and positrons into the throat of the collider at an energy of some 47 GeV, or about half the Z mass of 92 GeV. A set of magnets then deflects those bundles around one or the other side of the loop: positrons to the right, electrons to the left. On the far side the bundles slam into one another head-on, with the Z particles flashing into brief existence as a product of electron-positron annihilation. And then the decay products of the Zs are finally captured for analysis inside the Mark II detector, which surrounds the point of collision like a huge steel can.

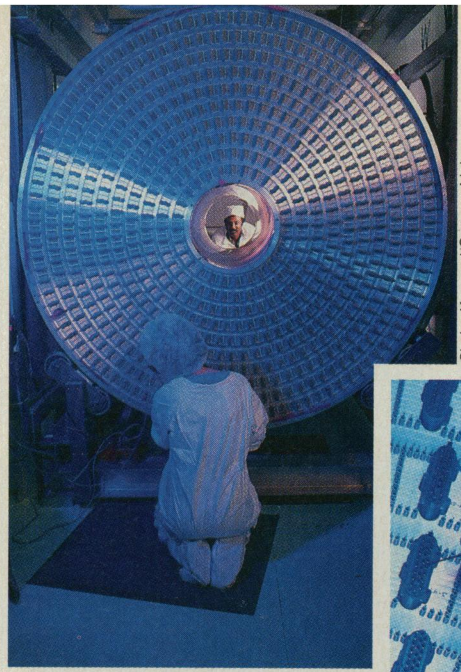
In practice, however, getting the aging linear accelerator and the new collider to work together has been an exercise in teeth-gnashing frustration. The very fact that the beams get just one chance to interact, for example, means that they have to be focused down into very tiny, very dense spots only 3 or 4 micrometers wide at the point of crossing. And that means, in turn, that the accelerator and the collider taken together have to be as finely tuned as a laser.

Thus the Troubles of '88: when the "Z factory" started its initial data run last summer, it sputtered and coughed and never made a single Z. The aging components in the accelerator were simply not up to the demands being placed on them. By midsummer, Richter felt compelled to put SLAC on a war footing. He persuaded the Department of Energy to kick in $2 million in emergency money and diverted another $1 million from the laboratory's noncollider programs. He likewise commandeered as many warm bodies from those programs as he could and put them to work fixing the worst of the collider's problems with a massive series of upgrades. Erratic microprocessors were replaced in the accelerator. Power supplies were stabilized. Collimators were installed to clean out contamination from stray particles reaching the Mark II. It took all winter.

Meanwhile, in what he still refers to only as "a very delicate matter," Richter fired the head of SLAC's accelerator division, Rae Stiening, and took over his job personally. "A lot of programs had to be changed, and a lot of money moved," he says, "and that's a lot easier if the lab director does it." Involving himself at this level of detail was undeniably awkward; as one physicist says, "If the head of the accelerator division asks a question, the person hearing the answer is also the director of the lab [SLAC]. You don't like telling him you've screwed up. So I suspect he sometimes has trouble hearing the truth." But Richter felt he had no choice. Stiening, for his part, declined *Science*'s invitation to comment on the matter.

In any case, the upgrades worked. As the physicists started tuning up the machine again in mid-February 1989 in preparation for a new round of data-taking, they could already sense they were on the right track. "People here were like hunters," says Andrew Hutton, head of the collider's beam delivery section and the man most directly responsible for making the machine work. "You felt the thrill of the chase."

But that just brings us to the second reason that things are tricky: not everyone at the collider is looking for Zs. For every experimental physicist eager to spend every possible second taking data, there is an accelerator physicist who would happily tune up and calibrate and tinker with the machine forever. The result is a more or less amiable tug of war between the two cultures. You can't make many Zs without a better machine, explains Hutton, an accelerator man himself, "but you can't make the machine better without working on it." The trick is to get the machine good enough and then force yourself to keep your hands off the knobs for awhile. "It's a whole new work style for us," he says.



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Close work. *A technician wires the Stanford Large Detector.*

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Hutton and his colleagues are going to get a lot of practice in that style, however. At the moment the collider is producing Zs at the rate of one or two per day when it is on its best behavior; their goal is to boost that to a reliable one Z per hour by the end of the summer. Soon, for example, they plan to double the number of particle pulses coming down the accelerator, from 30 per second to 60 per second. More slowly, they plan a steady increase in the population of the pulses, each of which currently contains about 10^{10} particles. And they will continue to twiddle with the collider magnets so as to sharpen the focus of the beams as they intersect.

Meanwhile, Dorfan and his colleagues on the Mark II will be accumulating Zs. If all goes well they should have roughly 1000 events by autumn, enough to determine the mass and decay of the Z with record precision. The decay rate will be particularly interesting, says Dorfan, because it counts the number of different kinds of neutrinos in nature: each new neutrino gives the Z a new way to decay and thereby ups the rate. Moreover, since each kind of neutrino is associated with its own "family" of quarks and leptons, a definitive count would give theorists a lot of help in understanding what is still an utter mystery: how many families of particles are there, beyond the three already known, and why do they exist at all?

Unfortunately, says Hutton, there are limits to what can be done by twiddling the knobs. So at the end of August or in early September, the collider will be shut down entirely for about 12 weeks for another major set of upgrades. The most notable improvements will include a new positron source that should boost the number of particles per pulse by near another factor of 5, and a new set of magnets that should up the pulse rate to 120 per second. No Zs will be forthcoming in that time, but the Mark II group is not complaining: if these new upgrades really do boost the rates by an order of magnitude, then the experimenters will make up the missing 3 months of data in a little over a week. By the summer of 1990 they should be well on their way toward 10,000 Zs, enough to start looking for exotic decay products such as supersymmetric particles or charged Higgs bosons.

By this point, Stanford's collider will still be an order of magnitude or so below the Z production rate being planned for LEP. But then, production rate isn't everything. As early as this fall, for example, the collider physicists plan to install the first components of a system that should ultimately allow them to generate "polarized" beams—that is, beams with all the electron and positron spins aligned in a chosen direction. This would allow them to make very precise and stringent tests of the various unified field theories. Sometime after the summer of 1990, moreover, they plan to replace the Mark II detector with a 4000-ton behemoth known as the Stanford Large Detector. Among other things, it should allow for a much better identification of the Z decay products than the Mark II, thus permitting a serious search for the neutral Higgs boson, which is thought to be a key player in the

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In the control room. *Beam delivery chief Andrew Hutton keeps the electrons and positrons focused as they race toward annihilation.*

unification of electromagnetism and the weak interaction.

In parallel with all this, the accelerator physicists are also using the collider to explore the technology of linear colliders in general, with a view toward pushing electron-positron physics into realms of energy that are simply not practical with conventional, circular machines. "LEP is already 27 kilometers around and it's getting ridiculous," says Hutton. In any given circular machine, a process known as synchrotron radiation will eventually cause the particles to lose energy as fast as the accelerator can supply it. Doubling LEP's 160-GeV energy would therefore require a quadrupling of its size, which would make it larger than the proposed Superconducting Super Collider. (If built, the supercollider's energy will be more than 100 times LEP's because it will use protons, which have much lower synchrotron losses.)

Thus the appeal of a linear collider, says Hutton: eliminate the synchrotron losses by eliminating the circular motion. In particular, he says, if two linear accelerators, each about 10 kilometers long, were pointed down each other's throats like muzzle-to-muzzle rifles, they could achieve a total collision energy of 1 trillion electron volts (TeV). That would be sufficient to bring forth not just Zs, but Higgs bosons, supersymmetry, "technicolor" particles—indeed, much the same kinds of high-energy exotica that the supercollider would be looking for. Moreover, because electron-positron annihilation events tend to be far less complicated than the massive splatter produced by colliding protons, a high-energy linear collider would be able to dissect those phenomena with far greater precision.

Basking in the afterglow of the first Zs, Richter and his colleagues are already thinking hard about how to actually build such a full-scale machine. Known variously as "the Next Linear Collider" or "the TeV Linear Collider," it is in an embryonic state at best, says Richter. In particular, there is still a great deal to learn about building power supplies that can provide sufficient accelerating muscle without an impossible price, and about the focusing of electron-positron beams at TeV energies. (The cross section would be measured in *nano*meters.) "The earliest time we could produce a credible proposal would be 1992 or 1993," he says, "and even then only if everything works well here."

On the other hand, the experience so far with the Stanford collider has already taught everyone involved a crucial lesson for taking that next step: "Be prepared!" says Richter. "For anything!"

■ M. Mitchell Waldrop

Can You Help the Mets by Watching on TV?

Physicist-philosopher-baseball fan David Mermin uses the Baseball Principle to make a point about the nature of reality

Einstein didn't like it. He called it "spooky action at a distance" and argued that no self-respecting universe would allow such behavior. But the behavior that Einstein did not like turns out to exist in our universe after all.

In 1981–82, French researcher Alain Aspect and collaborators did a series of experiments that proved that events in one place can be mysteriously correlated with events in a second region so far removed from the first that no direct communication between the two is possible. Right there in the laboratory was Einstein's "spooky action." Physicists are still arguing about the implications of the experiments.

Cornell University physicist David Mermin has a unique way to make some of these abstruse arguments accessible to the nonspecialist. He takes an interpretation of the Aspect experiment offered by Henry Stapp of Lawrence Berkeley Laboratory and rewrites it in baseball terms. The irreverent Mermin, who at one time crusaded to make "boojum" an accepted scientific term, finds that asking "Can you help the Mets by watching on TV?" opens the door to some rather deep questions.

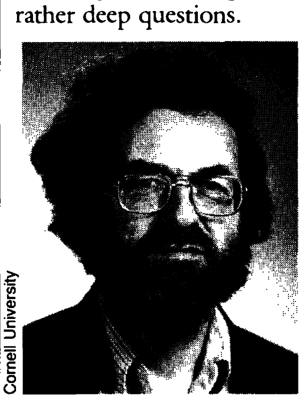
Most fans know in their hearts, Mermin says, that watching the game on TV makes no difference to the outcome. "What I do or don't do in Ithaca, New York, can have no effect on what the Mets do or don't do in Flushing, New York," Mermin says. "This is the Baseball Principle."

A pedant, Mermin says, might argue that what the Baseball Principle really means is that if one examined a large number of games, some of which the fan watched and others he did not, then statistically the team would perform equally well in the watched and unwatched games.

But Mermin means something stronger than a statistical statement. "Tonight, for example, whatever the Mets do will be exactly the same whether or not I end up watching the game." He calls this claim that the Baseball Principle applies to individual games the Strong Baseball Principle.

"Nonsense," says the pedant. You either watch the game or not, and you cannot possibly know what would have happened in the alternate case. It is impossible to test the Strong Baseball Principle, and a statement that cannot be tested has no meaning.

This is where you are wrong, Mermin replies. It is possible to test the Strong Baseball Principle—not in the world of baseball, perhaps, but in the realm of quantum physics. The Aspect experiments offer a



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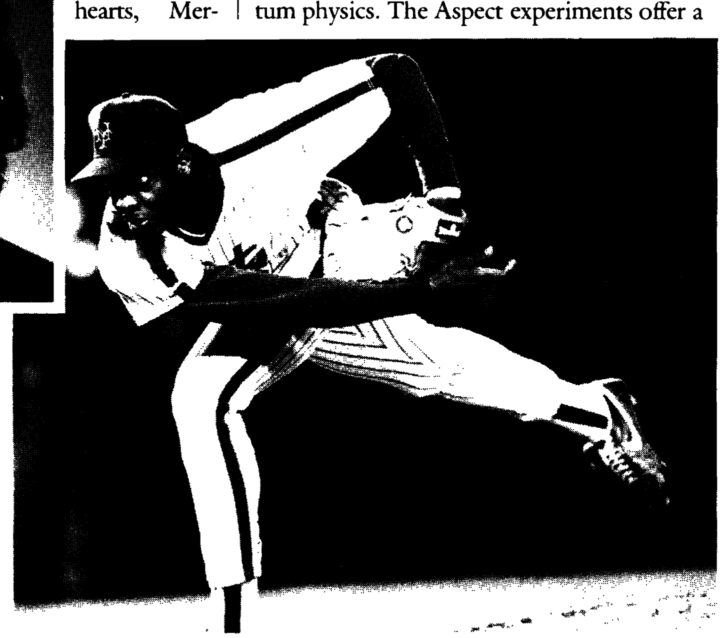

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Mets fan David Mermin *says that what he does or doesn't do in Ithaca, New York, can have no effect on what Dwight Gooden does or doesn't do in Flushing, New York. "This is the Baseball Principle."*