The SSC: Radical Therapy for Physics

Experimentalists and theorists in high-energy physics are running out of common ground. The SSC is their costly bid to work hand-in-hand again

AT A RECENT PARTICLE PHYSICS CONFERENCE at the University of British Columbia in Vancouver, an embarrassingly large number of experimental physicists walked out of a respected theorist's talk. His subject: the famous but highly speculative concept known as superstrings. What his listeners were fleeing wasn't the difficulty of the topic; after all, these were people who earlier on this perfect August day had forgone the sunshine for "the status of the standard model," among other talks. No, something else was wrong—something symptomatic of a sickness afflicting the whole field of particle physics.

Evidence of the malaise could be heard outside, behind the lecture hall. "Most of us hate superstrings," said one escapee. Others chimed in. "No one understands them." Worst of all: "No one can test them." The illness particle physics is suffering from, as the incident made clear, is a deficiency of experiment. The hoped-for cure: a heavy dose of experiment in the form of the Superconducting Super Collider (SSC).

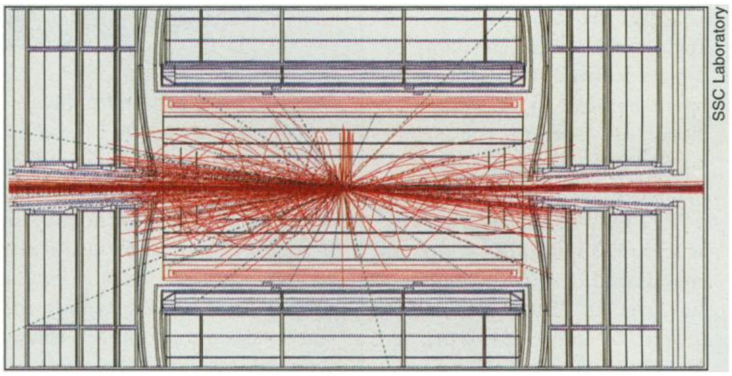
The limitations of existing accelerators are stifling the interplay of experiment and theory responsible for particle physics' rapid strides up until the early 1980s. Today, as theorists play in the untestable nine-dimensional world of superstrings, experimentalists are reduced to testing well-established theory at higher and higher precision—measuring the mass of the muon to a fraction of a percent, for example. The SSC, slated to be up and running by 1999, could make the theorists feel less irrelevant and the experimentalists less boring—albeit at a breathtaking cost.

Few projects in recent scientific history have been more controversial than this 50-mile behemoth in Waxahachie, Texas, with its estimated $8.25 billion in construction costs and $350-million-a-year operating budget. And though the SSC would collide particles with 20 times more energy than any of today's facilities, it faces the threat that a planned European facility at CERN, the Large Hadron Collider, might do the job almost as well and far more cheaply (see box). In making their case to the taxpaying public and to legions of skeptical scientists from other disciplines, promoters of the SSC have been uniting under the banner of as-yet-unseen particles, especially an elusive creature by the name of the Higgs particle. But a wide sampling of particle physicists interviewed by *Science* voiced another reason—less specific but no less urgent—for their plea.

"Politics can force you to say you are going for something well defined—the Higgs particle gives us a concrete goal," says Fermilab theorist Keith Ellis. But the passion with which he and his colleagues promote the SSC comes not from existing puzzles but from their eagerness to find something, anything, to prove current theory wrong. Particle physicists are searching for a new understanding—one that will reveal new patterns in the array of known particles and perhaps connect and unify the basic forces of nature. Now, however, they have next to nothing to go on. What they seek from the SSC is a surprise—a new puzzle whose solution could light the correct path to their goal.

High-energy physics is a victim of its own success. The so-called standard model—the existing body of theory describing particles and forces at the most fundamental known level—is causing terrible grief by working so predictably. The standard model reduces matter to six particles called quarks (which make up protons and neutrons) and six known as leptons (which include the electron and the neutrino), interacting through four forces: gravity, the strong and weak forces, and electromagnetism. Over the past two decades, physicists have created and studied every particle predicted by the standard model except for the top quark. And in the 1970s and early 1980s, experiments confirmed its prediction that the electromagnetic and weak forces are aspects of a single force.

Since then, the standard model has offered no comparable challenges—no fatal flaw physicists could attack in order to rebuild it as a better theory. Ever more precise tests of the predicted particle masses and interactions have kept agreeing with theory, to everyone's dismay. "At CERN, they have been doing precision tests, hoping that things wouldn't work," Ellis says. But the hoped for hints of new physics haven't materialized. "Everything works so wretchedly well we don't know what's going to happen next," says Ellis.

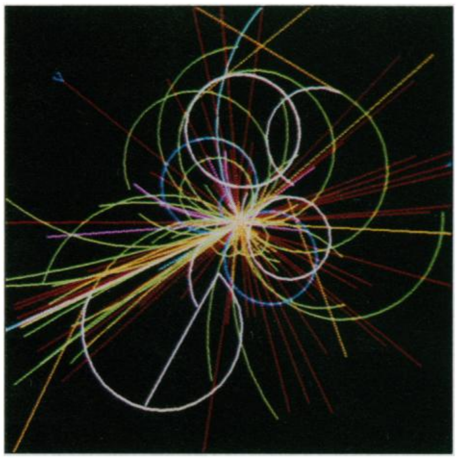


Preview of the Higgs? *The trail of the elusive particle is buried in the fallout of this simulated SSC collision.*

The deadly reliability of the standard model has even become a grim in-joke in the high-energy community. At last summer's CERN conference, theorist Sheldon Glashow of Harvard recalls, he told an audience that prominent experimentalist Carlo Rubbia was being punished for unwarranted bragging when he was made director of CERN—"a lab whose sole function is to verify eternally the predictions of the standard model."

But even though experimentalists' best efforts can't point to a way past the standard model, physicists are convinced there's life beyond its confines. The model, they say, just takes too much for granted. Two of the quarks plus the electron and neutrino are enough to explain ordinary matter, but nature throws in eight more oddballs, adding two additional families of quarks and leptons. "We can do fine without those other families," says Robert Peccei, a theorist from the University of California, Los Angeles. "Why are they here?"

Worse, all these particles present a seemingly senseless array of different masses. The standard model is at a loss to explain particle masses, says MIT theorist Edward Farhi—it



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The same old thing. *A collision in an existing accelerator is a fireworks of particles, but the patterns are familiar.*

treats mass as a free parameter. If you change the mass of, say, the electron, it has no effect on any other quantity; everything still works just fine. As a result, says Ellis, "We have no understanding of why the top quark, or any of the quarks, have the masses they do—some large and some small."

But physicists are driven by a belief that nature can't be that arbitrary. "The masses—that's a problem I've been beating my head against for 20 years and my head is tired," says Harvard theorist Howard Georgi. "It's maddening not to have an understanding of the pattern of masses." Clues to that understanding will emerge only when physicists step beyond known physics—and that, they say, will probably take the energy of the SSC.

Physicists' confidence in the SSC comes, ironically, from the standard model they are so eager to transcend. Even though the model yields no hints of any new physics, it does point to a general energy range where new phenomena might emerge. And since the model works so well in other respects, it's probably right about that as well, says Fermilab theorist Chris Quigg.

What physicists are staking their hopes on is the standard model's prediction that SSC energies will open a realm of physics characteristic of an earlier period in the universe. Physicists often equate higher accelerator energies with the first instants after the Big Bang, when particles crashed in a sort of multibillion-degree primordial soup. At first, explains Peccei of UCLA, all four forces were indistinguishable. Gravity became a separate force after 10^{-43} seconds, followed by the strong force at 10^{-31} seconds, he says. At about 10^{-10} seconds, the last two forces, weak

CERN's Horserace With the SSC

It is the year 1999, and the Superconducting Super Collider (SSC) is nearing completion. But, just as the giant machine is about to start smashing protons together at unprecedented collision energies, a dramatic announcement comes from across the Atlantic: One of the SSC's prize quarries, the Higgs particle, has been captured. The victorious hunter is the Large Hadron Collider (LHC), a synchrotron at Europe's CERN laboratory in Geneva. The announcement means that the SSC is left with the task of plodding through potentially interesting but less glamorous physics in the trillion electron-volt (TeV) energy range.

Although many physicists doubt that this scenario will come to pass—for one thing, the LHC has not yet even been approved—on paper, at least, CERN's proposed machine seems well suited to beat out its gargantuan competitor. Instead of spending years digging a new ring, CERN plans to put the LHC's twin proton beams in the same tunnel now occupied by the Large Electron Positron (LEP) ring. Its designers plan to make up for a somewhat limited collision energy of 15.4 TeV, less than half what the SSC is expected to deliver, by running the LHC at a "luminosity"—roughly the number of particle collisions per second—nearly 40 times that of the SSC. (Higher luminosities improve the chance of detecting new particles because more are created.) It's also far cheaper ($1.4 billion vs. $8.25 billion in construction costs). Most important, perhaps, the LHC's schedule calls for it to begin producing data in 1998—a full year earlier than the SSC.

Such an approach is not without risks, of course. The lower energy of the LHC could place the new physics that researchers are seeking just out of the LHC's reach—for instance, if the Higgs boson weighs in at more than about 600 GeV, or supersymmetric particles at greater than 1 TeV. (Because much of the total energy in any proton collision creates a spray of extraneous "background" particles, the total useful energy for creation of a particle like the Higgs is much less than the accelerator's maximum.) And for all the elegance and economy of the concept, in practice, the LHC faces some tough challenges in stealing a march on its U.S. rival.

First, the CERN Council probably won't make a final decision on whether to build the LHC until late 1992 or early 1993. Then there are major technical obstacles to be overcome. Since the LHC's superconducting magnets must fit in LEP's narrow tunnel, engineers planned to run both LHC beam tubes through the same iron yoke and to clamp their magnet coils with a single collar. But, as an LHC review committee noted last May, data from magnet testing show that this "two-in-one" collar has been unable to hold the coils immobile against the pull of their enormous fields: 10 tesla, compared to 6.6 tesla for the SSC's magnets. Since at 1.8 K even a slight shift produces enough friction heat to destroy the superconductivity, the committee recommended separating the collars for the two coils, a setback that could take several months to a year to resolve. CERN engineers are now building prototype magnets with separated collars, but haven't decided whether or not to use them in the final design.

LHC's high proposed luminosity may also cause some problems for detector designers, who must figure out how to filter out extremely high background levels and accompanying synchrotron radiation in order to focus on particles of interest. Designing such detectors will clearly be a formidable task, as even CERN director general Carlo Rubbia admits: "We still don't know how to filter all these events and how to deal with 300 to 400 particles produced during an interesting event." If LHC is to begin taking data on time, researchers must build their detectors in just 6 years—2 years less than their counterparts at the SSC.

If Rubbia manages to surmount these obstacles—and one review committee member notes that "every machine [CERN] has built turned on on schedule and has worked perfectly"—then the LHC would have a shot at scooping the SSC in some important discoveries. Even if that happens, however, SSC supporters insist that their machine will have plenty of interesting physics to do. Theorist Sidney Drell of the Stanford Linear Accelerator Center, who likens the TeV energy range to a tangled, unknown forest, puts it this way: "LHC is making a pass through that forest, along one trajectory, one trail. The goal may be there, or it may not be. If they don't find it, they won't know why." Only the more powerful SSC, he says, will be able to answer the "why" after the "what."

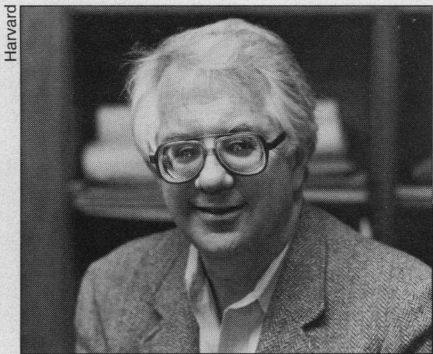
■ DAVID P. HAMILTON

With reporting by Suren Erkman in Geneva.

and electromagnetic, went their own ways.

According to the standard model, the SSC's 40 trillion electron volts of energy should be enough to carry physicists back by one epoch, reunifying the weak and electromagnetic forces. They will thus be able to replay the divergence of those two forces—the instant of "symmetry breaking." And that divergence of forces, they think, may hold clues to the enigma of mass.

That belief rests on the physicists' concept of force-carrying particles called bosons. In our four-force era, physicists equate the electromagnetic force with an exchange of massless photons, while they see the weak force as an exchange of very heavy particles, the W and Z. But in the higher energy realm of the SSC, where the two forces merge, all three bosons are predicted to be massless.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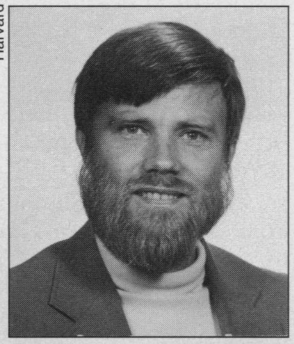
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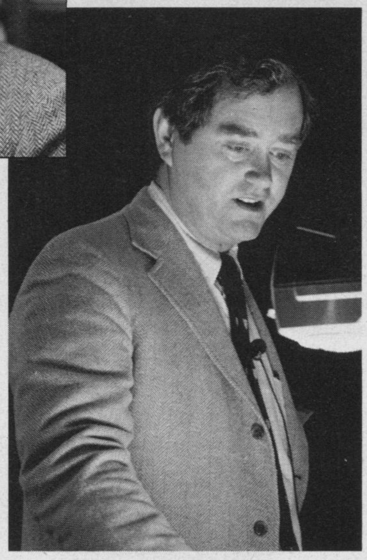
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Desperately seeking data. *Theorists Glashow (above), Georgi (top right), and Quigg (right).*

Physicists' best guess now is that all particles are inherently massless; they acquire mass from some outside agent. Some kind of field—like an electric field— pervades space, and each particle's interaction with this field determines its mass. At the instant of divergence between the weak and electromagnetic forces something happened to that fabric to give rise to the masses of the W and Z—and to those of other particles as well.

So far, physicists have come up with only one theory explaining how the W and Z particles gained their mass: the so-called Higgs mechanism. If the theory holds, a Higgs particle—the embodiment of a pervasive Higgs field—should await discovery in the SSC. But even though this particle has come to serve as a nutshell scientific justification for the SSC, most physicists would just as soon do without it.

"The worst thing that could possibly happen," says Glashow, "is that we'd find the Higgs particle and nothing else." One reason, he explains, is that the Higgs theory alone only addresses the general mechanism by which particles became massive, without revealing any pattern to the haphazard masses of the particles. As a result, physicists would much rather stumble on hints of a more encompassing mass mechanism.

Worse than the Higgs mechanism's lack of explanatory power is the fact that finding the Higgs particle wouldn't free physicists from their current impasse and get them beyond the standard model. Since the Higgs is considered to make up part of the standard model—a sort of loose end—finding it would amount to another confirmation of current theory. "We would still have no idea what experiments to do to build a better theory," adds Glashow.

But there's some consolation for physicists unenthusiastic about the Higgs mechanism: Many researchers view it as implausible in any case. Says Ellis: "I don't think anyone really believes that that's what is going to come out—or that that's all that's going to come out." Georgi points out that the mechanism requires the Higgs particle to lack spin—a fundamental property found in all other elementary particles. For that reason, Georgi considers the Higgs mechanism an "outlandish" possibility.

There is one salvation for the Higgs particle: It could be a composite of other particles. Unlike such presumably indivisible entities as quarks and leptons, composite particles can have a total spin of zero. Some researchers raise the possibility of a Higgs particle made of ordinary quarks, including the still unseen top quark. But others imagine that the Higgs might consist of exotic new particles, which would make it a creature of physics beyond the standard model.

Those theorists picture the Higgs as just one combination of an entirely new stable of particles called techniparticles, posited as part of a speculative scheme called technicolor. The discovery of such a Higgs particle or of its techniparticle constituents—massive counterparts to known particles called techniquarks and technigluons—would break the tyranny of the standard model. Technicolor "would embody, swallow up, subsume the standard model," says Quigg. It would also add a new force to the list, but despite these additions it would simplify the picture, just as the discovery of quarks reduced a once-baffling array of particles to combinations of a small set of building blocks.

As an improvement on the standard model, technicolor is vying with a whole class of "supersymmetric" theories, which posit particles called squarks and sleptons—another set of counterparts to the known particles. And the mathematical structure of supersymmetry provides a bridge to still more ambitious theories that describe particles and forces not just at the energies of the SSC, but at the even higher—perhaps never attainable—energies at which the strong force is expected to be united with the weak and electromagnetic forces.

By describing all three forces in a single set of formulas, these "grand unified theories" (GUTs) would open the way to what has become a holy grail of physics—a unification of fundamental forces. And beyond these GUTs, which leave gravity out of their unification, lie so-called theories of everything, such as superstring theory. Over the last 20 years theorists have flooded the market with these encompassing theories, says Fermilab's Quigg, and no one knows which ones have anything to do with reality. "We need experiments to help us select the right path," he says.

If some new SSC discovery does point out a path, it could mark a revival of a malaise-stricken pursuit in particle physics. Unifiers who flung themselves into the search for a GUT 20 years ago are losing their enthusiasm. Georgi, who along with Glashow made one of the most famous unification attempts, says he has now lost interest in the whole unification idea because it lies so far out of reach of experiment. "You give up a lot when you can't test theories with an accelerator," he says. "What you want is something your experimental friends can shoot down."

The experimentalists who walked out on the superstrings talk in Vancouver would agree. "At times I've asked the superstring theorists why they are working in an area that is so far removed from experiment," says Fermilab theorist Melvyn Shochet. "The answer they give is that they don't have any other experimental puzzles." Perhaps the SSC will provide one, once again letting experimentalists and theorists work on common ground. ■ FAYE FLAM