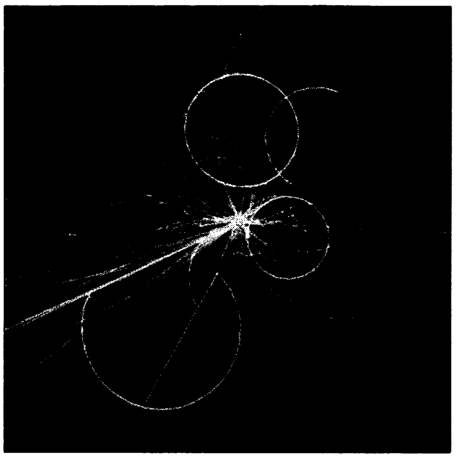
treats mass as a free parameter. If you change the mass of, say, the electron, it has no effect on any other quantity; everything still works just fine. As a result, says Ellis, "We have no understanding of why the top quark, or any of the quarks, have the masses they do—some large and some small."

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.



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

Fermilab

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.