B Factories Have Physicists Buzzing

The factories offer a way of doing front-line physics at a modest cost. No wonder then that SLAC and Cornell—and the SSC and Fermilab—want one

WITH THE SUPERCONDUCTING SUPER Collider looming large on the horizon, the United States' existing high-energy physics laboratories are facing a time of crisis. By current estimates it will take in excess of $8 billion over a decade to get the SSC into operation. Until that machine is completed, physicists at the existing labs will be scrambling to upgrade their facilities so that they can remain competitive and continue doing front-line physics research. The question is, How do they get the wherewithal to succeed with the SSC project swallowing up so much of Washington's largess?

The obvious answer is to undertake projects that both physicists and lawmakers in Washington find compelling. But there's a catch: Particle physics projects that sexy have become few and far between, as hard to find as the elusive elementary particles themselves.

Enter the "B factory," an ingenious proposition that would produce particles known as B mesons by the billions. In February, both the Stanford Linear Accelerator Center (SLAC) and Cornell's Laboratory of Nuclear Physics rushed off proposals to Washington requesting funds to build B factories. Such machines would provide physicists with an unprecedented opportunity to probe the source of the fundamental asymmetries of matter and antimatter that led to the existence of the universe as we know it. And they could be built for the modest sum of $100 million to $200 million—less than one-fiftieth the cost of the SSC. "It's a bargain basement price for high energy physics these days, an unbeatable bargain," says Maury Tigner of Cornell.

Although it seems only a penurious congressman could turn down such a bargain, only one lab, if any, is likely to see its dream of a B factory fulfilled. The history of physics is littered with once great laboratories, whose times have come and gone for good. The question now is whether two more labs are going to join those famous has-beens.

SLAC, in particular, has fallen on hard times, its illustrious history notwithstanding. In the 1960s, for example, the lab helped elucidate the nature of quarks, and in the 1970s it shared in the discovery of the J/psi particle. The center's Linear Collider, which was turned on in 1988, is an impressive technological achievement, but it has had its share of troubles and has been overwhelmed by the European competition, the Large Electron-Positron Collider at CERN (The European Laboratory for Particle Physics), which came on line in 1989 (see box on p. 1417).

SLAC's long-term future, says Burton Richter, the lab director, is the "Next Linear Collider"—a machine that promises to be as powerful as the SSC at a fraction of the cost. But it still has a billion-dollar-plus price tag, and that means that it can't be built in the near future. "The SSC is sucking up so many resources," Richter says, "that you can't even think of a national program for another billion-dollar class machine until [the SSC] is nearly over."

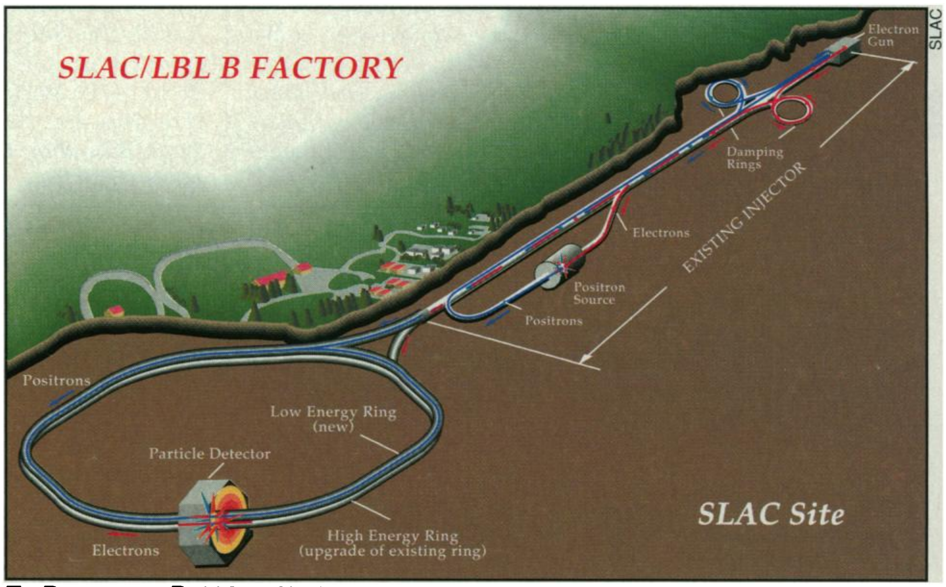
That leaves SLAC vulnerable in the near term. And to make matters worse, the U.S. budget reconciliation act last October cost SLAC $9 million out of its $139-million budget. The lab had to mothball its electron-positron storage ring for 1991 and lay off 66 of its 1400 employees. SLAC, Richter says, "has lots of morale problems."

Building a B factory is the best solution to what Stanford physicists call the "data now" problem—how to keep doing front-line physics until the SSC is complete and funds become available for more expensive items like the next linear collider.

But then Cornell physicists have come up with the same idea. And that institution's Laboratory of Nuclear Studies, although only one-tenth the size of SLAC, has a possible advantage: A decade-long tradition of studying B mesons. Lab director Karl Berkelman insists that losing the B factory to SLAC would not be the end for his institution. He concedes, nevertheless, that if that should happen, he and his Cornell colleagues might have to pack up the show and "do our physics at the SSC or wherever the action is."

What a B factory would do is collide electrons and positrons at an energy of about 10 billion electron volts (GeV) producing B mesons, which are particles containing B quarks. Although B mesons were discovered back in 1977, they have never been made in large quantities. And physicists would particularly like to have large numbers of B mesons because they could be used to study the peculiar effect known as CP violation, which is one of the last remaining mysteries of the Standard Model, the set of accepted theories that explains the structure and interactions of matter.

CP violation was discovered in 1964 by Val Fitch and James Cronin, who won the 1980 Nobel Prize for their work. While the researchers were studying the behavior of the



To B or not to B. *If SLAC's dreams come true, the lab will build the B factory shown here. But Cornell wants a B factory, too, and only one lab is likely to prevail.*

particles known as K mesons, or kaons, they noticed something unexpected, a violation of the principle of symmetry that proposed that particles and antiparticles should behave identically, provided that "you look at one of them in the mirror," as physicist Lincoln Wolfenstein of Carnegie-Mellon University puts it. But Fitch and Cronin found that the rate at which a neutral kaon turns into its antiparticle differs by about 0.2% from the rate at which the neutral antikaon turns into a kaon. That's a minute effect in the kaon system. Berkelman describes it as "a very small difference occurring with a particle that has a rare and fleeting existence."

Indeed, CP violation was much too small to be systematically investigated in kaons, but it has profound implications. As Andrei Sakharov pointed out in 1968, this tiny asymmetry between matter and antimatter might account for why the universe seems to be composed exclusively of matter. Or, as B factory proponent Richter puts it: "CP violation is why we're here."

And if that isn't reason enough to go after CP violation, there's another enticement as well. The effect is a window into the physics of the Higgs boson, one of two fundamental particles that have not yet been trapped by the high-energy physicists' mega-accelerators—and the main target of the SSC. Says James Bjorken of Stanford, "The parameters that characterize CP violation are about as fundamental as you can get. This field is not going to go out of fashion."

The High Energy Physics Advisory Panel (HEPAP) agrees. In 1990 the panel, charged with charting the path of high-energy physics through the pre-SSC years, "strongly" endorsed the idea of a B factory. HEPAP, however, ranked the concept after the SSC; a new injector for the Fermilab Tevatron, which wants to use it to look for the other remaining fundamental particle, the top quark (see box); and a healthy exploitation of present Department of Energy (DOE) facilities. But physicist Pier Odonne of the Lawrence Berkeley lab (LLB) points out, "Those recommendations were made a little over a year ago. At that point we didn't have a proposal."

They have one now because it's only been in the past 2 or 3 years that systematic characterization of CP violation even began to look practical. The idea itself only dates back 10 years to a paper published in ***Physical Review Letters*** in 1981 by physicists Tony Sanda and Ashton Carter, who were then at Rockefeller University. Sanda and Carter proposed that since B mesons are nothing but kaons with the strange quark replaced by the much heavier bottom quark, the B mesons might reveal considerably more about CP violation than kaons possibly could. They predicted that in certain decays of neutral B

Will Fermilab Get Its Upgrade?

The need to upgrade aging accelerators is not limited to labs on the two coasts. Officials at the Fermi National Accelerator Laboratory in Batavia, Illinois, where the bottom quark was discovered in 1977, have said they'd like to modernize their facilities by replacing the 20-year-old main accelerator ring with a new particle injector built in a separate tunnel. But to researchers at the lab, the improvement may be more than a timely facelift. "Without the new injector, Fermilab is dead," says one highly placed Washington, D.C., physicist who is responsible for securing funding for new physics projects.

Fortunately, then, the prospects for the new injector—and Fermilab's survival—look good at the moment. The injector's cost, $177.8 million, is modest, at least by the standards of high-energy physics. And last year, the High Energy Physics Advisory Panel (HEPAP) gave the new injector its top priority recommendation. (HEPAP's 1990 report did not consider the Superconducting Super Collider, a top priority in previous years that had already been approved.)

If Congress accepts the panel's recommendation, Fermilab will once again have a shot at some of the hottest particle physics going. The lab's physicists—who previously gave the world such advances as the first superconducting accelerator and the highest-energy proton-antiproton collider, would be able to increase the frequency of proton-antiproton collisions in Fermilab's Tevatron accelerator more than fiftyfold. This upgrade, coupled with a few other major modifications, such as development of a new particle detector, would improve the researcher's chances of catching the massive top quark. The Higgs boson, the SSC's target, and the top quark are the two remaining elements of the Standard Model, and therefore of great interest to high energy physicists.

And that's not all. Advocates of the Fermi upgrade, most notably including Nobel physicist Leon Lederman, the lab's most recent past director and now professor of physics at the University of Chicago, and John Peoples, the current director, say the enhancement would also allow study of the elusive tau neutrino and k mesons, thereby providing a better understanding of the difference between ordinary matter and antimatter. What's more, they claim, the new, improved Fermilab would also be able to do B meson studies similar to those planned for the "B factories" now being proposed for Cornell and the Stanford Linear Accelerator Center (see accompanying story).

But even though the injector has received HEPAP's blessing, the schedule for building it is by no means a sure thing. Although it has made the president's budget for fiscal year 1992, negotiations with Congress, and wrangling within the scientific community itself over which project or projects should be given the go-ahead and how fast they should be funded might still derail the project. The Department of Energy (DOE) already has SLAC's recently submitted B factory proposal, and if its budget remains relatively constant, as seems likely, then it may have room for strong support of only one major new physics project other than the SSC. Then again, DOE may choose to extend its limited resources by funding more than one project but at a slower pace.

Lederman doesn't see the B factory proposals as a threat. Ever the optimist, at least in public, he points out that HEPAP previously ranked B factories after Fermilab's injector, and he believes it unlikely that the panel will revise its recently stated priorities. "The committee knew the B proposals were coming and they could have withheld judgment until those proposals were in hand," he says.

But even Lederman acknowledges that in the coming years there will be pressure to shut down aging accelerators in favor of newer, more splendid models, such as the SSC. He notes that HEPAP has been recommending that strategy since it got into the assessment business in the mid-1960s. So there is ample reason for even the optimists to be developing frayed nerves. Consider the fate of the Princeton-University of Pennsylvania accelerator. When it opened at Princeton in 1963, it was the ultimate atom-smashing tool in high-energy physics. In 1971, however, the Atomic Energy Commission decided to concentrate its resources on the national accelerators and withdrew funding from the Princeton-Penn facility. Despite efforts to gain support from alternative sources, the facility was turned off in 1972. It succumbed to the wrecking ball a few years ago. Fermi's physicists don't want to see their high-energy lab succumb to that sort of a low-energy demolition derby.

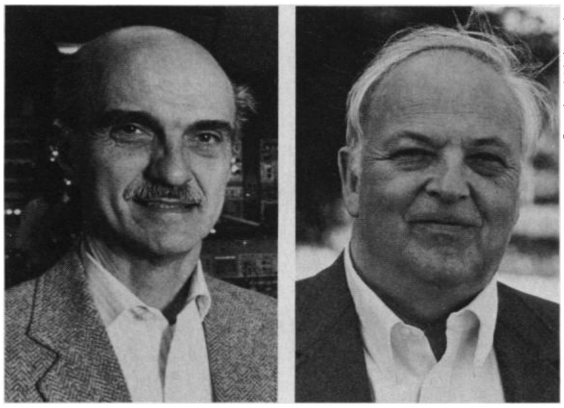
■ ANNE SIMON MOFFAT

mesons, the effect of CP violation could be surprisingly large, as great as 20%, or 100 times greater than in K mesons.

Sanda and Carter suggested that physicists could therefore study the asymmetry in the decay of the neutral B and its antiparticle. The way to do that was to tune an electron-positron machine to 10.56 GeV, the resonance energy of the upsilon 4S particle, which decays spontaneously into a B meson and anti-B meson. The B and anti-B would live for a trillionth of a second before decaying themselves. CP violation could then be quantified by measuring the decay trials of the B and anti-B.

In 1981, says Stanford's Bjorken, that was an "off-the-wall idea" because it was experimentally impossible. The problem was that the upsilon 4S is only slightly heavier than the two B mesons combined, so the kinetic energy given to the two mesons in creation is small. Physicists calculated that the mesons would travel barely 20 nanometers before decaying, and no experiment had the resolution to identify particles that travel so short a distance. Just 2 years later, however, the outlook for the experiment began to brighten. In 1983, the Mark II experiment at SLAC indicated that the B meson would travel 1000 times farther than expected. And 4 years after that, the ARGUS experiment at DESY in Hamburg, Germany, followed by CLEO at Cornell, found that the frequency of B-anti-B conversions was also greater than expected. They happen about 20% of the time.

Taken together, the two results meant that the effect of CP violation in the B system might be large enough to measure after all. "It went from something very, very out of reach," says David Hitlin of Caltech, "to something only two orders of magnitude out of reach, and then people started thinking, How do we do that?"



Cornell University

Stanford University

Competing directors. *Cornell's Karl Berkelman* (left) *and SLAC's Burton Richter both want a B factory.*

The problems that had yet to be overcome were now all experimental. For starters, a B factory would need enormous luminosity to make the billion B mesons that physicists deemed necessary for the measurements they wanted to make. Then there was the still considerable problem of resolving the infinitesimal tracks of the B decays. In 1987, LBL's Odonne suggested that this could be accomplished by colliding beams of two different energies, say, 9 GeV in one and 3 GeV in the other. As a result, the B mesons would be created with a hefty kick away from the point at which the two beams intersect, making their decay tracks much longer and easier to resolve.

That was the good news. The bad news was that such an asymmetric collider would require two beam pipes—and conventional colliders have only one. With two pipes, the particles have to be taken from their orbits into collision and then brought back into orbit, which is not an easy proposition. "When we first started saying we need to make an asymmetric accelerator and have to increase the luminosity by some factor of 30 to 100, the first reaction was 'you're out of your mind,'" says Hitlin, who is involved in the SLAC proposal. "But we convinced ourselves it was not insane."

In November 1989, a group of California physicists led by Jonathan Dorfan of SLAC, Odonne, and Hitlin also managed to convince the program committee at SLAC that an asymmetric B factory was not insane. In January 1990, SLAC and LBL initiated a 1-year feasibility study, the result of which is a 700-page document that represents a fully engineered machine design. The labs submitted this document to the Department of Energy on 18 February. "The machine is buildable," says Dorfan. "It takes great care in engineering, but it's buildable."

Cornell physicists also concluded that an asymmetric B factor is feasible, submitting their proposal to the National Science Foundation on 21 February. Both labs hope to begin building in 1993 and to have their machines up and running by 1997.

Each group has its own pluses and minuses. Both propose to build their B factories by adding a second beam pipe to existing accelerators. But Cornell's design is more conservative, Berkelman says, in that it leaves open the option of running the machine in a symmetric mode, if for some unforeseen reason the asymmetric mode doesn't work. A symmetrical machine would, however, take years longer to do the same physics as an asymmetric machine.

Berkelman also points out that Cornell has something that SLAC doesn't: a state-of-the-art B detector that would only have to be upgraded at a cost of about $10 million. SLAC proposes to spend between $50 million and $60 million building a new detector.

Richter counters that the number of users wanting to get in on a B factory would almost necessitate turning Cornell into a national laboratory. SLAC already is a national lab and has more facilities for users, plus a larger tunnel that would make it easier from an engineering point of view to build the ring for the needed second beam. Tigner in turn replies that Cornell could build its machine for less, because the Cornell accelerator tunnel is smaller, requiring a smaller installation.

Who will be the winner in this competition, which is by all accounts still a friendly one? At this point, nobody knows. If NSF and DOE go their separate ways on evaluating the SLAC and Cornell proposals, the final answer may come down to which agency has the deeper pockets. "You can imagine both winners or both losers," says Berkelman. Or HEPAP could be called in to compare the two proposals and recommend which is better.

Then there is another and unexpected source of competition. It may be possible to do B physics in machines like the SSC and Fermilab's Tevatron after all. These machines, which collide protons and protons or protons and antiprotons, create Bs by the bucketful, but they come awash in a sea of background. The question is, can they be detected? The answer used to be no, but Fermilab recently proved that wrong, though it hasn't detected nearly enough Bs for B factory experiments.

An international collaboration of some 80 physicists, led by Nigel Lockyer of the University of Pennsylvania, has proposed a B experiment for either the Tevatron or the SSC. Lockyer points out that the SSC will produce a million times more Bs than any B factory, which should give the SSC a big advantage, provided that the detection problem can be solved. To do that, Lockyer says, they'll need a futuristic detector with 100 times the sensitivity of the next generation of Tevatron detectors, and 2000 times the computing power. "The issue in our case," he says, "is does the technology exist for the experiment? For the B factories, it's can you believe the accelerator?"

For Washington, the issue appears to be whether the funding agencies can come up with the money for a B factory anywhere. John O'Fallon, the director of high-energy physics at DOE, says the B factory proposals are in for a long road of reviews now and anything can happen. "It's exciting physics," says O'Fallon. "That's what the community tells us again and again, and we believe it. So we'll take a hard look at it."

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