Nearly departed? Parts of SLAC's PEP-II collider could be shipped to Italy to build a new collider for high-precision experiments, called SuperB.

PARTICLE PHYSICS

Competing Teams Plot Two Different Paths to a New Particle Smasher

To make a new collider, physicists in Japan plan to push an existing machine to its limits. Others in Italy hope to cobble one together from old parts and a bright idea

Many a teenager has dreamed of transforming a jalopy into a gleaming hot rod. Now, a team of physicists from the United States and Italy has proposed a project that sounds as unlikely. Using parts from an old particle smasher, they plan to build a new one that will crank out data 100 times faster than the original machine, consume less power, and possibly find hints of particles so massive that no collider could produce them directly—not even the new highest energy collider that will turn on in Europe this summer. But the project, dubbed SuperB, isn't the only dragster in this race: Physicists in Japan plan to upgrade their existing machine to do the same work.

SuperB would be built at the University of Rome "Tor Vergata," near Frascati National Laboratory in central Italy. But most of its parts would come from the PEP-II collider at the Stanford Linear Accelerator Center (SLAC) in Menlo Park, California, which was shut down in April—even though some say it still had plenty of science in it. SuperB team members hope SLAC and the U.S. Department of Energy (DOE) will donate PEP-II and the accompanying BaBar particle detector to the project as an in-kind contribution worth about $200 million. "Here's a contribution that doesn't cost anybody anything," says David Hitlin, a team member from the California Institute of Technology (Caltech) in Pasadena. "Doesn't it make sense to leverage your assets?"

SuperB would serve as a foil to the world's mightiest accelerator, the Large Hadron Collider (LHC) soon to power up at the European particle physics laboratory, CERN, near Geneva, Switzerland (*Science*, 23 March 2007, p. 1652). By smashing protons into protons, the LHC aims to blast massive new particles into existence. In contrast, SuperB would collide electrons and positrons at lower energies to produce a flood of familiar particles, and the details of their decays could reveal hints of new physics.

The approach, called precision physics, has the potential to be "real cowboy physics," says Thomas Browder of the University of Hawaii, Honolulu. Such a collider might spot rare decays that would rewrite the standard model of particle physics or even find hints of particles beyond the grasp of the LHC, Browder says.

But SuperB has competition. Browder is one of about 400 physicists working with the KEKB collider and the Belle particle detector at the Japanese laboratory KEK in Tsukuba. They plan to upgrade that machine to create Super KEKB. "This was put into the official plan of KEK" in January, says Masanori Yamauchi, a particle physicist at KEK, "but the government has not given approval yet."

Heavy hints

Because mass and energy are equivalent, physicists can pop a massive new particle into existence by colliding well-known ones at sufficiently high energy, as they aim to do at the LHC. But massive new particles can also cast shadows in the decays of far less massive ones, especially those made up of fundamental bits of matter called quarks.

According to the standard model of particles, the matter around us consists of the up quarks and down quarks that make up protons and neutrons, electrons, and wispy electron neutrinos. This first "family" of particles is copied twice over, so there are heavier quarks of four more "flavors": charm and strange, top and bottom.

Consider the decay of a particle called a B meson, which contains a massive bottom quark and a lighter antiquark. Thanks to the uncertainties of quantum mechanics, the meson roils with other particles popping in and out of "virtual" existence within it, even ones more massive than the meson itself. So if there are new particles lurking over the horizon, they will flit about inside the meson and may reveal their nature by affecting the way the B meson decays.

Physicists have used this approach to narrow in on new particles before. For example, in the 1980s, studies of B mesons, which are only five times as heavy as a proton, indicated that the then-hypothesized top quark was much heavier than previously thought, says Peter Krizan of the University of Ljubljana and the Jožef Stefan Institute in Slovenia. That inference proved correct when the top quark was found in 1995 and weighed in at 180 times the mass of a proton.

Both the KEKB collider and SLAC's PEP-II were built to do just this sort of work. Since 1999, the two "B factories" have pumped out scads of B mesons, and experimenters working with the BaBar detector at SLAC and the Belle detector at KEK have studied a slight asymmetry between B mesons and their antimatter counterparts, anti–B mesons. That discrepancy, known as charge-parity (CP) violation, had been previously seen only in lighter K mesons.

BaBar and Belle proved that, to a precision of a few percent, the standard model's explanation of CP violation is on the mark (*Science*,

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13 October 2006, p. 248). That was both a huge victory and a disappointment for physicists, as the theory contains far too little CP violation to explain why the universe contains gobs of matter but essentially no antimatter. "We all know that the standard model is a fantastic theory," Krizan says, "but we also know that it's fantastically wrong."

Both the SuperB and KEKB teams now want a "super flavor factory" that will crank out far more B mesons, as well as mounds of particles called D mesons and tau leptons, heavier cousins of electrons. All that data would allow for even more precise tests of the standard model's CP-violation scheme. More important, says Hitlin, it might reveal rare decays that turn the theory on its head. "The point is *not* doing what you did before but better," Hitlin says. "It's looking for these very rare decays."

Such studies would complement the LHC's direct search for new particles. If the LHC sees plenty of new particles, a super flavor factory would probe how they couple to quarks and other known particles. If the LHC sees nothing, then precision physics offers the best hope of sensing particles beyond its grasp. "These precision measurements are basically the only tool you have that shoots far beyond the mass reach of the LHC," Krizan says.

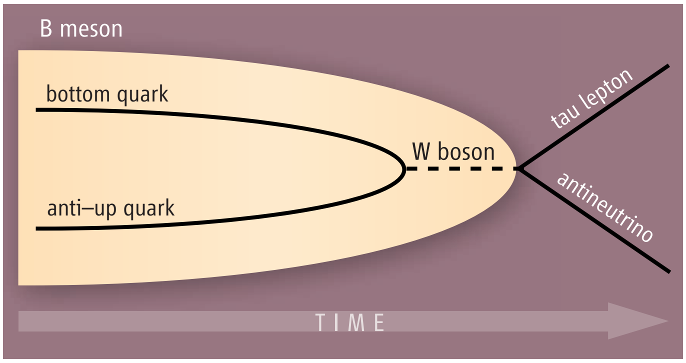
Huge currents, tiny beams

The SuperB and KEK groups are taking different approaches to designing their machines. Similar to PEP-II, the KEKB collider comprises two circular accelerators that cross in the middle of the associated detector, one carrying electrons in one direction and the other carrying positrons in the other. "Our design is kind of brute force," says Yamauchi. "We put more and more electrons and positrons into the rings."

KEK physicists would boost the current in the electron ring from 1.2 amps to 4.1 amps and in the lower energy positron ring from 1.6 amps to a sizzling 9.4 amps. They would squeeze the beams to half their current size and employ a new technique to reduce the tendency of the crossing beams to disrupt each other. The path to Super KEKB is "very, very predictable from our present machine," says Katsunobu Oide, an accelerator physicist at KEK. By the time KEKB shuts down, probably in 2010, it will have created a billion B–anti-B pairs. Super KEKB would produce pairs at least 10 times faster and eventually make 50 billion of them.

Instead of packing in more particles, SuperB would use greatly compressed beams, thereby increasing the rate at which electrons and positrons collide, which is called the luminosity. "We get 100 times smaller vertical size at the interaction point, and that means 100 times more luminosity with the same beam current," says Pantaleo Raimondi, an accelerator physicist at Frascati who dreamed up the scheme. At the start, SuperB would crank out data five times as fast as Super KEKB's initial rate.

SuperB would collide beams only 35 nanometers across. To make such tiny beams, researchers must very precisely arrange both the magnets that steer the beam around a ring and those that focus it, Raimondi says. The SuperB design borrows from work on "damping rings" being developed to compress the beams in the proposed International Linear Collider (ILC), a multibillion-dollar straight-shot collider that would study in detail new particles discovered at the LHC.



Subtle signals. A B meson decays into a tau lepton and an antineutrino. The probability for the decay would differ from standard model predictions if there are new particles that could fill the role of the familiar W boson.

To limit the cost of SuperB to roughly $500 million, researchers plan to reuse the PEP-II hardware from SLAC. In fact, physicists had proposed upgrading PEP-II where it stands as early as 2001. Those plans were squeezed out by tight budgets in DOE's particle physics program and by the U.S. community's desire to push to host ILC. Now that a PEP-II upgrade is "not in the cards," the lab may be willing to part with the machine, says Steven Kahn, SLAC's director of particle physic and astrophysics. "We're not seeing any major hurdles to our saying yes to this," he says. SLAC has asked the Italian National Institute for Nuclear Physics (INFN) to formally request the equipment, Kahn says.

Pros and cons

Each approach has both strengths and potential weaknesses. The Super KEKB design requires no conceptual leaps, but circulating nearly 10 amps of current presents its own challenges. The extent to which the beams disrupt each other increases with the number of particles in them, says John Seeman, an accelerator physicist at SLAC, so achieving the luminosity increase may be tricky. The high currents would also increase power consumption of the complex from 40 megawatts to 80 megawatts, raising yearly operating costs by tens of millions of dollars.

In contrast, the SuperB collider would use only 20 megawatts, less than PEP-II did. But steering its tiny beams into each other may be tough, Oide says. "To collide such tiny beams is not trivial," he says. "It's many orders of magnitude more difficult than producing a single nanometer-sized beam." SuperB researchers will have to limit vibrations at the crossing point to just 3 nanometers, Oide says. However, if the tiny-beam scheme seems likely to work, then KEK researchers may simply adopt it, too.

Politically, SuperB team members have a tougher row to hoe, as they are asking the Italian government for hundreds of millions of euros to build a new laboratory to house the collider. A subpanel of the European Committee for Future Accelerators is studying the plan. If both it and the CERN Strategy Group, which keeps the road map for European particle physics, give the plan high marks, then INFN will ask the Italian government for funding. Physicists hope to begin detailed design work as early as next year.

In contrast, KEK researchers already have a lab and machine. KEK is negotiating for funding with Japan's Ministry of Education, Culture, Sports, Science, and Technology. Researchers hope to shut down KEKB in 2010 and spend 3 years building Super KEKB. At the least, they hope to use the money saved from KEKB's operating budget to fund $220 million in improvements. The full upgrade would cost much more, but Japanese researchers are reluctant to say how much.

Given the financial demands of the LHC and other projects and tight funding all over, many say the community can likely afford only one super flavor factory. "In the end, the country that wants the machine the most and puts up most of the money will get it," Seeman predicts. Will it be Italy or Japan? Physicists may know within a year.

–ADRIAN CHO