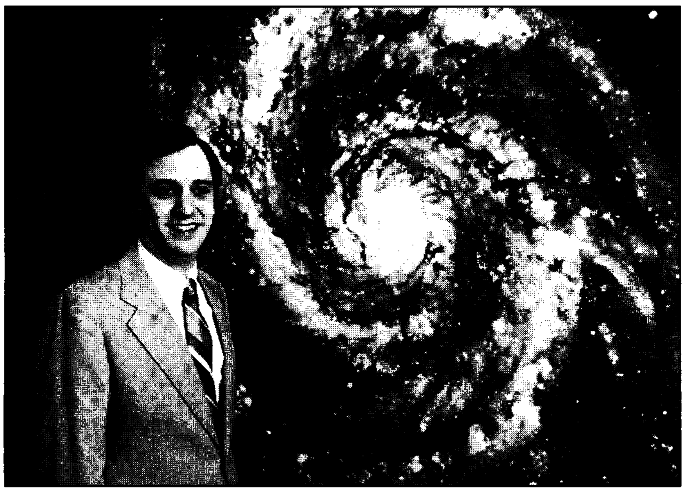
Netherlands argued that Gott's scenario for sneaking around the cosmic speed limit—the speed of light—is actually in flagrant violation of it. Jackiw and his colleagues determined the velocity of the strings' combined center of mass. Although you might expect their center of mass to be stationary, because the strings are moving in opposite directions, the warping of spacetime actually leads to a velocity that would exceed that of light, the theorists say.

In an interview with *Science*, Jackiw added a second broad objection, based indirectly on the grandfather paradox. Even though Gott's closed timelike curves would be rare, they would shatter the concept of causality, for which we have ample evidence, he says. Time travel simply violates the evidence of our senses, Jackiw contends.

Gott is unfazed by either objection. The center of mass representation that Jackiw and his colleagues rely on to accuse him of violating the cosmic speed limit is invalid, he believes, because the strings, individually, are moving at less than the speed of light. The group's argument, he says, amounts to saying,



PRINCETON

Time-machine designer. Theoretical physicist J. Richard Gott has touched off a lively debate.

"We do not like what CTCs imply for physics, so CTCs are unphysical constructs."

As for Jackiw's other complaint, Gott concedes the point but insists it rules out closed timelike curves only in the present universe, not at some point in the past or future. To bolster his case, Gott points to a paper in the 15 January *Physical Review D* by Caltech physicist Curt Cutler. Cutler's paper shows, according to Gott, that a normal causal universe can briefly develop a closed timelike curve that then disappears, restoring sense to the universe.

While Gott fends off the published challenges, others are looming. Even now another paper by 't Hooft is circulating in the physics community as a preprint. The preprint argues that even in closed universes—where there is enough mass to halt expansion—closed timelike curves are impossible. In a closed universe, there would be no shortage of mass for building the time machine, but—in an ironical twist—there might not be enough time. The universe would collapse in a "big crunch" before a spaceship could travel around the strings and return to its starting point, 't Hooft claims.

Time tourists. Gott's scenario will also have to withstand the skepticism of Stephen Hawking, the noted theoretical astrophysicist at the University of Cambridge. Hawking has long argued against the possibility of time travel. For example, he drew upon quantum effects to dismiss a 1988 proposal by Caltech theoretical physicist Kip Thorne that wormholes—theoretical tunnels connecting distant points in spacetime—could serve as gates to the past. In an effort to prohibit time machines of any design, Hawking has just completed a manuscript, called "The Chronology Protection Conjecture," arguing that the laws of physics forbid closed timelike curves. Somewhat tongue-in-cheek, Hawking cites as "strong empirical evidence" for his conjecture the fact that "we have not been invaded by hordes of tourists from the future."

In a more serious vein, Hawking argues that, in general, closed timelike curves sow the seeds of their own destruction by creating a feedback loop in which small fluctuations in the energy of the vacuum travel back in time. At the end of the closed timelike curve, infinite energy builds up, distorting spacetime and disrupting the time travel mechanism. Thorne calls Hawking's work "a very powerful result" and explains the Catch-22 in time this way: "You kill [a closed timelike curve] the moment you create it."

Under this sort of withering assault, Gott's notion may finally collapse. But based on past experience, there's every indication that future generations of physicists will return to the Wells conceit time after time. As several physicists told *Science*, wrangling about such possibilities—or impossibilities—can sometimes lead to fresh insights about general relativity and, more generally, the nature of the universe. Remarks Thorne, "If we can understand how nature protects herself from time travel, we would understand space and time more fully." And after all, one physicist sheepishly admits, "There isn't a whole lot to do in fundamental physics right now."

–John Travis

PARTICLE PHYSICS

CERN's New Detectors Take Shape

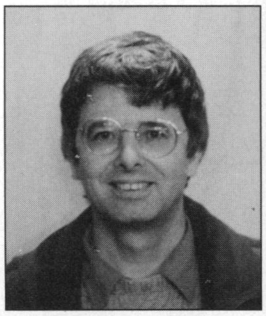
When Carlo Rubbia presides over a physics meeting—as he did last month at Evian-les-Bains, France—he rules like a stern father at a family gathering. Physicists had come to Evian to display their proposals for the Large Hadron Collider (LHC), a European megaproject rivaling the United States' Superconducting Super Collider (SSC). The LHC will be built at CERN, in Geneva, in a tunnel that now houses an existing accelerator. And Rubbia, as director-general of CERN, was definitely the man to please if you wanted your proposal for doing science at the LHC to be included.

The contenders were grouped into four teams, each made up of hundreds of investigators collaborating on a single detector design. The CERN management, especially Rubbia and research director Walter Hoogland, insists that the teams were presenting only preliminary ideas, and that all the participating scientists will have an opportunity to get on an approved detector. But for many at the Evian meeting, the stakes were high. All knew that only two of the four proposals would be approved, a decision that will cause leaders to drop out and months of labor to go to waste. Rubbia promised to appoint a committee to do the winnowing, but he clearly will have a role in the decision himself.

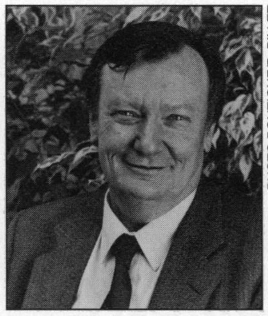
So each team arrived at Evian with a spokesman to sell the merits of its particular design. The cast of protagonists included Peter Norton of England's Rutherford-Appleton Laboratory, Peter Jenni of CERN, Michael Della Negra of CERN, and Sam Ting of MIT.

The new particle detectors they were offering to build at LHC will be similar in concept to those at existing accelerators, but more sophisticated in design. These massive devices embrace intersections where bunches of speeding particles crash head-on from opposite directions, millions of times per second. Each collision sends out an explosion of energy and matter, and the detectors are supposed to capture and identify every shard of this debris. To do this, they employ thousands of tons of materials in an interlocking, Rube Goldberg arrangement of tricks and traps—liquid argon chambers, exotic crystals, and powerful electromagnets. A jungle of cables and wires connect the detectors to computers that sift the output for traces of exotic particles that may have lived for no more than a nanosecond.

The task of capturing these events will be



CERN



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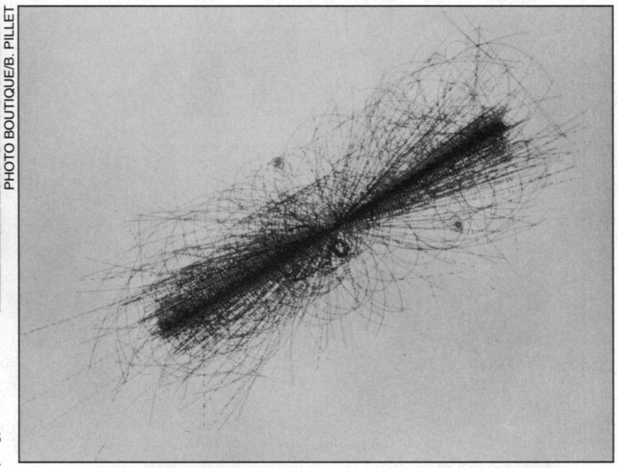

Shotgun wedding? Michael Della Negra *(left)* and Sam Ting *(middle)* may face a forced union of their proposals, performed by CERN head Carlo Rubbia *(right)*. Far right: a detector's-eye view of a simulated particle collision in the proposed LHC.

magnified in the LHC detectors, because they will have to record collisions that occur millions of times a second—hundreds of times faster than in existing experiments. In both the SSC and LHC, collisions will occur so fast that the byproducts won't even have time to travel the few meters to the detector walls before more collisions occur, sending out more particle showers. To avoid being deluged, the new detectors will use split-second electronic "triggers" that quickly discard all unpromising catches.

Making the technical challenge even more difficult, designers have been told they must do the job as cheaply as possible. Each knows that Rubbia and the CERN management will weigh technical promise of the detector design against cost. And no one at Evian seemed to believe anyone else's cost estimate. Accusations flew back and forth as one team questioned another's pricing assumptions. Unlike the presentations on design, which had a serious air, the sessions on cost resembled a high-stakes game show.

Behind curtain number one was the Ascot detector: spokesman, Peter Norton. This specialized detector, Norton explained, would concentrate on the toughest-to-detect debris particles, the muons. Muons hardly interact with ordinary matter at all, and yet physicists expect their presence to signal the creation of the new particles—especially the famous Higgs bosons—for which everyone is hunting. The estimated cost was a middling 395 million Swiss francs ($280 million).

Behind curtain number two was Eagle, an all-purpose detector. "The key word is balance," said spokesman Peter Jenni. Eagle is being designed to pick up a wide variety of particles. Its price: high, at 500 million Swiss francs, though Jenni maintains that Eagle is actually a bargain at that price.

Behind curtain number three was CMS, another all-purpose design, but one that would give priority to muons, electrons, and photons—particularly important parts of the collision debris. Spokesman Della Negra said his team plans to use exotic crystals to trap and measure these particles. The price: another middle-range option at 395 million Swiss francs. The fact that the estimate came out exactly the same as Ascot's was "pure coincidence," according to Della Negra.

Contestant number four was a device called L3+1, a used model, designed for the lab on a tight budget. It is a rebuilt version of Ting's L3 detector, already running on the LEP accelerator at CERN. Ting told the audience that his design would cost only 50 million Swiss francs, a fraction of the cost of the others—a savings to be gained, according to Ting, by relying on existing parts. But Rubbia wasn't buying. Before Ting stepped down, Rubbia jumped up and rushed to the back where he exchanged excited words with another physicist, ending with "This won't even save us 10%!"

Carlo Rubbia argues for two different detectors operated by rival research groups, because, he says, competition "is essential to science."

At the end of the meeting Rubbia called on all the teams to submit more detailed plans, known as letters of intent, by August. By then, he promised to have a committee formed to guide the needed reorganization. But the realignment may begin even before then. Some of the scientists, worried that their team might not succeed, were already looking around in the hope of merging forces with a competitor and avoiding a total loss. Some numbers of the Eagle and Ascot groups immediately started making tentative overtures toward marriage.

But two of the four teams look incompatible: those led by Della Negra and Ting. Their two projects—CMS and L3+1—don't have enough common ground to come together, participants on both sides say. Yet Ting has an optimistic vision for his group: He says he expects the scientists on all four collaborations to separate, re-form, and rally around two designs—one of them his own. He confidently explained that his plan will save so much money that it is a natural choice.

Ting's assessment didn't jibe with the views of many others, especially Della Negra of CMS, who said his collaborators aren't rushing to join Ting's project. Many say they find Ting a difficult leader. "People in my collaboration are extremely afraid to work with Ting," Della Negra says. He adds that he plans to keep his collaboration together for the time being, though he says Rubbia and Hoogland may try to "force a marriage" between his group and Ting's. In this case it might take a shotgun.

Another challenge facing the L3 team may be to overcome the skepticism of Rubbia himself. "We need two new detectors," said Rubbia in an interview with *Science*, with the emphasis on new. He added that he doesn't want the current L3 dismantled because the lab needs it for the ongoing LEP experiment.

A few scientists argue that CERN should take the money-saving approach of building just one detector. Most, however, are pushing for two, to assure credibility. The results of particle experiments come in a chaotic mess of debris tracks that can be easily misinterpreted. "We need two in order to confirm findings," says meeting director Gunther Flugge. "We don't want to make any discoveries that aren't there." CERN scientists haven't forgotten the time they found the (still undiscovered) top quark a few years back and then retracted the claim.

Rubbia also argues for two detectors run by rival groups, because he says that would fire up the spirit of competition that is "essential to science." To keep the prices down, he is pushing an evolutionary approach. He would like to start with the bare bones of a system that could pick up the glamorous new discoveries, such as the Higgs boson, then add refinements as needed in stages to do more detailed studies. Rubbia is known to be a competitive leader himself, and this is his strategy for beating the SSC to glory.

–Faye Flam