deliberately encourages close rivalry, for example, by requiring that all potentially interesting data be analyzed by two separate teams completely independently.

"If both teams come up with the same results, we can already be much more sure that there is not a mistake," says Mannfred Steuer, a physicist from the Massachusetts Institute of Technology who works with Ting on the L3 detector. "Competition [between the different experiments] is a good thing, because it will ensure that one gets the results very fast, and also that they are unbiased."

The results obtained in the first few months of operation will be important for more than their scientific significance. They will also be used by CERN director Rubbia to decide what type of upgrading of LEP in the mid-1990s he should try to persuade the member states to back. This will be high on the agenda when research ministers meet to discuss CERN's future early next year.

There are two main possibilities in the medium term. One is to increase the energy levels in the LEP ring (a move that would require applying for new planning permission from local authorities). The other is to introduce polarized beams, a step already being planned at Stanford.

Looking further into the future, the 14 member states will also have to decide what type of support to give to Rubbia's proposal for a second, superconducting ring in the LEP tunnel. This would turn LEP into a Large Hadron Collider capable of producing collisions at around 10 TeV; this energy range approaches that of the proposed Superconducting Super Collider in the United States—but, according to LEP officials, at about one-fifth the cost of that mega-machine.

It will be no easy task to squeeze the money for LHC out of governments for whom high energy physics no longer has the same glamour it once did. But Rubbia seems determined to put some of this glamour back; despite the cuts, for example, the advertising firm Saatchi and Saatchi has already been brought in to advise on how best to stage the official opening of LEP later this year, with guests ranging from the King of Norway to British Prime Minister Margaret Thatcher.

For most CERN physicists, however, the pomp and glamor of such a ceremony will be a side-show to the real action. After 10 years of design work and construction all eyes are on the performance of LEP as it slips into action in the next few weeks. Whatever happens, there is certain to be a great deal of work to do and hundreds of pairs of hands put to the task.

■ DAVID DICKSON

Another Piece of 3.14159 . . . ?

In 1666, Isaac Newton turned some knobs on his newly invented calculus and cranked out a decimal approximation to the ancient number pi—the ratio of circumference to diameter of a circle. "I am ashamed to tell you to how many places of figures I carried these computations, having no other business at the time," he later wrote. The figure was 16. If Newton was ashamed, then David and Gregory Chudnovsky might well be mortified: the two Columbia University mathematicians have computed 480 million digits of pi.

The Chudnovskys' feat eclipses the previous record of just over 201 million digits, set last year by Yasumasa Kanada of the University of Tokyo. If *Science* tried printing their result, the digits would fill up every page of every issue for the rest of the century. So you might ask: Why would they do this?

One reason for computing digits of pi is pure competitiveness and what can only be called the Mount Everest syndrome: because it's there. The Chudnovskys maintained silence during the calculation, not even telling the people at IBM or Cray exactly what they were doing, lest the competition dedicate a machine or two to the same task.

But there's a practical use for their work, as well. For one thing, there's nothing like a good run of pi digits to shake down a new computing system. For another, you can investigate a variety of number-theoretic and statistical hypotheses regarding pi this way: for instance, the relative frequency of various digit strings. The Chudnovskys' result allowed them to improve an analytic theorem regarding rational approximations to pi.

So if you accept the importance of this work, you may come to the question: how in the world did they do it? Part of the how, of course, is computers. The Chudnovskys carried out their calculations on a CRAY 2 at the Minnesota Supercomputer Center in Minneapolis and on an IBM 3090-VF at the IBM Yorktown Heights Research Center in New York. The rest of the how is pure mathematics. "In order to compute a number well, you have to know it intimately," says David Chudnovsky. Their calculation is based on a formula which the Chudnovskys discovered in 1984, relating pi to an infinite sum of rational numbers. The new formula was inspired by one discovered earlier this century by the Indian mathematician Srinivasa Ramanujan. William Gosper of the Symbolics Inc. in Palo Alto, California, used the Ramanujan formula in 1985 to obtain a short-lived record 17 million digits of pi. Both formulas stem from deep relationships in number theory and algebraic geometry.

But what if a cosmic ray or a power surge or a speck of dust on a disk messed something up in the calculation—how would you ever know? "We have an absolutely sure-fire way of validation and verification of the calculations," David Chudnovsky says. The verification is based on deep number-theoretic properties of the infinite sum, which they proved only last year. It can be thought of as a sophisticated version of the old accountants' trick of checking calculations by casting out nines; for the Chudnovskys a large set of prime numbers do essentially the same thing.

The Chudnovskys were extremely careful in handling the data. "We deposited on every media—disk or tape or anything else—the data together with a complete set of keys. . . . This means that every time we wrote in and every time we wrote out, we were checking whether we were correctly writing in and correctly writing out," David Chudnovsky says. "Out of all the computational time, over 90% of it went on verification, and the real run was under 10% of CPU time—which shows that our algorithm was pretty good."

Finally, there's the question, Where do we go from here? The answer to that one is that inherent in the Chudnovsky victory is the seed of its eventual defeat. A key new feature of their approach, the Chudnovskys say, is that it is expandable: more digits can be added on demand. By that they mean that you don't have to start from scratch to beat them, you can use their own method to pick up from where they left off or at any point in the chain of digits. So the procedure can actually be farmed out, with independent computers contributing to the calculation. That possibility evokes perhaps the grandest aspect of the Chudnovsky vision: a "pi chain letter" leading to a multibillion-digit decimal expansion of pi. The burghers of Oklahoma, who once tried to eliminate by legislation all the decimal places from pi because it was too complicated, will not be pleased. ■ BARRY A. CIPRA

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