Back in business

The focus of activity in high-energy physics is about to switch from CERN, near Geneva, to Fermilab in Illinois. Sarah Tomlin sampled the atmosphere, as excited physicists prepared their Tevatron accelerator for action.

FERMILAB

Smile please: the DZero team strikes a pose.

On a bright January afternoon at the Fermi National Accelerator Laboratory near Chicago, more than 200 physicists are gathered in 'the pit' — a huge chamber 15 metres underground. They are part of a 500-strong team that has, over the past five years, lovingly rebuilt DZero, one of two giant detectors at the Tevatron, Fermilab's main particle-accelerator.

The physicists are gathered for a photo-call, and there is a buzz in the air. The 5,000-tonne detector, some three storeys high, is ready to be rolled into the path of the Tevatron's particle beams. And on 1 March, when the Tevatron is switched on, DZero and its sister detector, CDF, will become the centre of the universe for high-energy physics — a position they should occupy for at least five or six years. "This is where there's going to be really big discoveries made," enthuses Joe Lykken, a theorist at Fermilab. "You can have surprises in other kinds of experiments, but there's no substitute for probing the high-energy frontier."

Fundamental *frisson*

Under any circumstances, the weeks preceding the reopening of the world's most powerful accelerator would be an exhilarating time. But events last autumn at CERN, the European Laboratory for Particle Physics near Geneva, have provided an additional *frisson*. CERN's Large Electron–Positron (LEP) collider recorded four events that gave tantalizing evidence for the most elusive of subatomic particles, the Higgs boson. With a mass of 115 GeV, or 115 times the mass of a proton, the Higgs is thought to give other particles their mass. And it is the next major quarry for high-energy physicists. LEP is now being dismantled, having missed its chance to secure the discovery. And that leaves the field open for the Tevatron.

Then there is Fermilab's role as the standard-bearer of US high-energy physics. Since 1993, when Congress cancelled the Superconducting Supercollider (SSC) project, the future of high-energy physics has been tied closely to CERN and its Large Hadron Collider (LHC), which should start running in 2006. But the revamped Tevatron will provide a brief window during which Fermilab will be the centre of attention. And that could prove crucial, as US physicists try to convince their political paymasters that the next big machine, beyond the LHC, should be built in the United States. "Fermilab is an ideal site for any of the future machines," argues Michael Witherell, the centre's director.

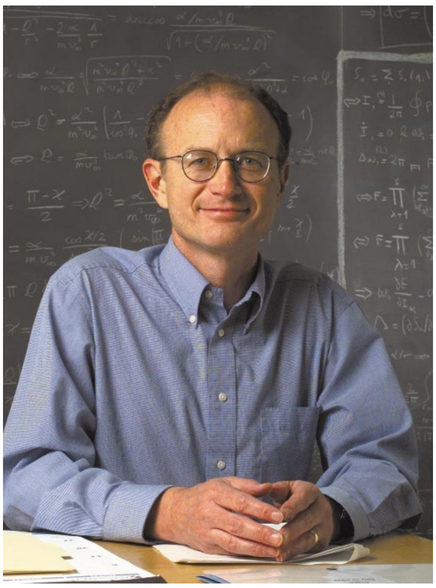
Gold standard

For the past 30 years, the theory of the basic constituents of nature — the Standard Model of particle physics — has been rigorously tested in accelerators around the world. And physicists have now discovered the full set of elementary particles predicted by the Standard Model.

There are two basic kinds of particles, building blocks of matter (fermions) and carriers of a fundamental force (bosons). The last piece of the puzzle, the tau neutrino, was discovered last summer at Fermilab, by physicists studying data from Tevatron experiments done in 1997, in which beams of high-energy protons were fired at a tungsten target[1]. This followed the Tevatron's previous triumph, the detection in 1995 of the freakishly massive top quark[2,3] — which has almost the same mass as a gold atom.

Despite these successes, the Standard Model is actually little more than a recipe. Although physicists have a list of the Universe's fundamental ingredients, no one can explain why they are present in the quantities we observe. Furthermore, a little extra bit of magic is needed to give the recipe substance. This is the Higgs field, which permeates everything, giving particles their mass. Detecting its signature particle — the Higgs boson — is the closest physicists can get to proving that the Higgs field exists. "In some sense, the top quark and the tau neutrino are the end of a generation of discoveries," says Witherell. "And the Higgs is really the first of the next."

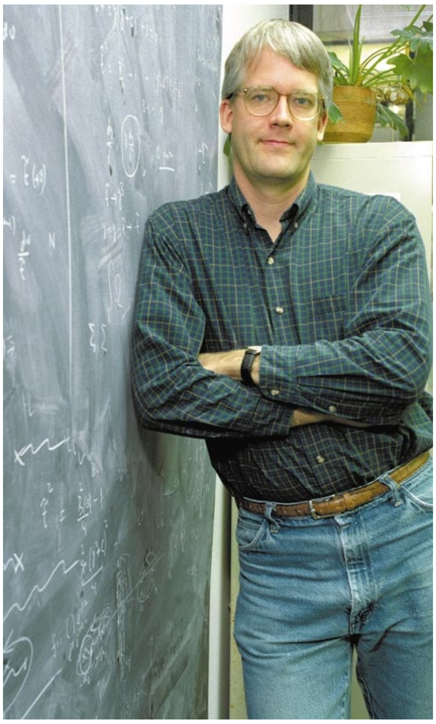
Fermilab's physicists will hunt for the



FERMILAB

Michael Witherell: the hunt is on for the Higgs.

FERMILAB



Joe Lykken: expects great discoveries.

Higgs in the debris that results when protons and antiprotons, both moving at close to the speed of light, collide head on. Since the end of the last collider experiments at Fermilab in 1996, a new $250-million main injector has been built, increasing the intensity of these beams by a factor of 20. The detectors have had a $200-million makeover, so that they can handle up to 10 million collisions per second.

Up close, CDF and DZero are astounding. Stand inside one of these behemoths and you can only marvel at their complexity. Each detector has a million electronic elements that can track the positions of particles. More than 1,200 kilometres of cabling carry away electronic signals, or feed cooling liquids or tracer gases, into the detectors. Through the middle of all this runs the Tevatron's 25-mm beam pipe.

Analysing data from the proton–antiproton collisions for signs of the Higgs will be more challenging than the task that faced physicists at LEP. The electrons and positrons smashed together at LEP are elementary particles, but the Tevatron's protons and antiprotons are effectively bags of quarks and antiquarks. When they collide, the result is a lot messier and harder to interpret. "You could get a Higgs boson the first day you turn on the accelerator, but to really know that you have a discovery takes years," warns Lykken.

The Tevatron will generate more collisions than can physically be recorded on tape. So out of the millions of collisions each second, the physicists plan to store only the 50 most interesting. The decisions on which ones to record will be made by 'triggers' — three levels of electronics and software systems that will sort out rare sightings from humdrum events. The bottom quark, in particular, is a strong indicator of new physics. "It's crucial to Higgs searches," says Witherell.

Al Goshaw, co-spokesman for the CDF experiment, hopes the team will have its first serious results by 2002. But no one is expecting the Higgs to reveal itself that quickly — indeed, its discovery may have to wait for another upgrade, in which the Tevatron's beam intensity will be boosted a further five- or ten-fold, planned for 2004.

Desperately seeking SUSY

Despite the kudos surrounding the Higgs, many of Fermilab's physicists are even more excited by the possibility of the Tevatron uncovering evidence for an exotic theory that lies beyond the Standard Model. "A lot of theoretical work shows that the Standard Model is a patched together, ugly theory," says Lykken. According to this view, it may actually be embedded in a more elegant theory called supersymmetry (SUSY).

If SUSY is real, then every particle in the Standard Model also has a supersymmetric partner — the selectron for the electron, the photino for the photon, and so on. SUSY is attractive because it provides a way to unite fermions and bosons, which differ in a property called 'spin'. Some of its predicted particles should have masses comparable to the top quark, and might be within the Tevatron's reach. SUSY also predicts several 'flavours' of Higgs boson, each with a different mass.

But even stranger possibilities exist. Some physicists hope that the Tevatron will yield evidence for extra spatial dimensions. As many as 11 extra dimensions are required by string theory, which is a contender for a deeper theory unifying the puny force of gravity with the other forces of the Standard Model. String theorists argue that we do not see these extra dimensions in our regular three-dimensional world because they are all rolled up very small.

Extra dimensions would probably show up in the Tevatron through their interaction with gravity. Like other forces, gravity is thought to be carried by a particle, yet to be detected, called a graviton. But with extra dimensions, huge numbers of extra gravitons could be created in high-energy collisions[4], which may reveal themselves through their collective effects. For example, they might show up as missing energy in a collision, if a particularly heavy graviton disappears into another dimension.

In short, no one can be quite sure what the Tevatron will discover. "It's not guaranteed that we will find any of these things," says Lykken. "But boy, it would be very disappointing if it didn't find at least one of them."

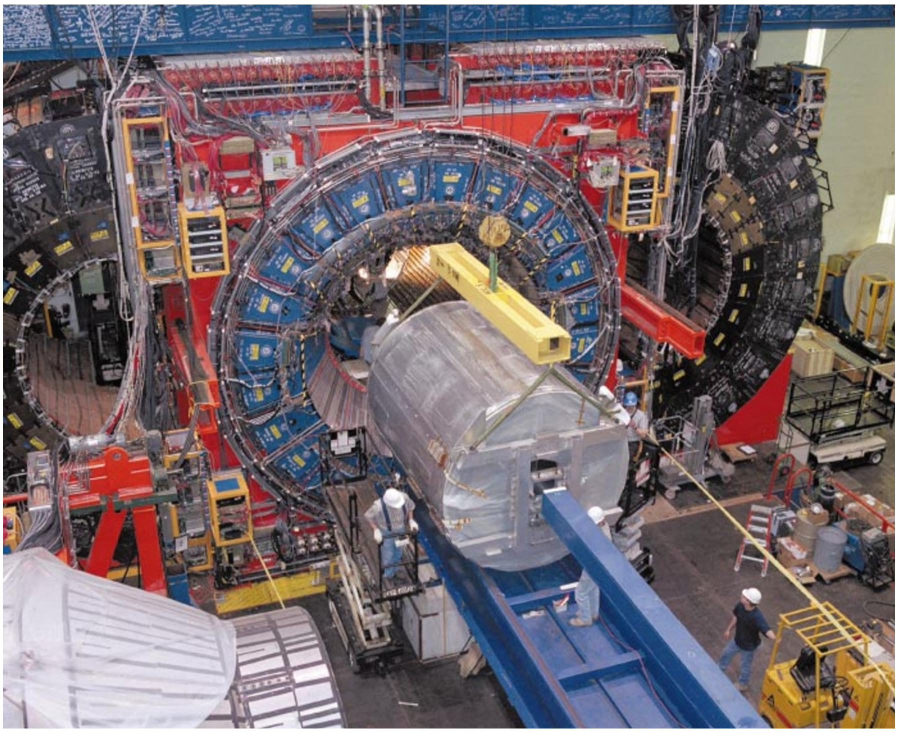
Amid the excitement and anticipation, however, there is one worry. According to one physicist, the LHC's start date hangs over Fermilab "like the sword of Damocles". With funding for the 2004 accelerator upgrade yet to be secured, there are still fears that the Tevatron could miss its chance to bag the Higgs. The clock is already ticking. ■

Sarah Tomlin is associate News & Views editor at *Nature*.

1. DONUT Collaboration *Phys. Lett. B* (in the press).
2. Abe, F. *et al. Phys. Rev. Lett.* **74,** 2626–2631 (1995).
3. Abachi, S. *et al. Phys. Rev. Lett.* **74,** 2632–2637 (1995).
4. Arkani-Hamed, N., Dimopoulos, S. & Dvali, G. *Phys. Lett. B* **429,** 263–272 (1998).

http://www.fnal.gov

FERMILAB



Detective agent: the CDF central tracker is installed following its multi-million-dollar face-lift.