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Issues and Events

Disappointing Collider Performance and Tight Budgets Confront Fermilab With Tough Decisions

The goal remains to get the most physics out of the world's highest-energy accelerator before that title passes to CERN at the end of the decade.

The final shutdown of the Large Electron-Positron Collider at CERN three years ago left Fermilab's Tevatron collider as the world's only accelerator at the so-called energy frontier of particle physics. And the Tevatron will retain that unique status for another five years or so, until the baton passes to the Large Hadron Collider, now under construction in the vacated LEP tunnel.

Figure

The 6-km-circumference Tevatron ring brings countercirculating beams of 1-TeV protons and antiprotons into collision. By 2008, the LHC should be providing experimenters with proton- proton collisions at seven times that energy. For that reason, and because the Tevatron is now the only high-energy game in town, the US particle-physics community and its funders are particularly anxious that the Fermilab collider turn out as much data as possible before the LHC starts producing physics results.

If that's the goal, the Tevatron's performance over the past few years has been--by consensus--disappointing. In 1996, the machine was turned off for a scheduled three-year shutdown, to install a new 150-GeV injector ring (the so-called main injector) and other major upgrades that were expected to raise the collider's event rate by something like a factor of five (see the photo above). Another purpose of the main injector was to let the collider run simultaneously with fixed-target neutrino and kaon-beam experiments.

The first disappointment was that the shutdown, not helped by tardy funding, lasted two years longer than anticipated. And when the collider did finally start running again in 2001, it took almost a year to get the event rate back up to its pre-shutdown level. Even now, the typical event rate is only 2.5 times what it was just before the five-year shutdown.

Two cancellations

In recent months, internal and external reviews of the tribulations at Fermilab have set in motion reorganizations, reanalyses, and revitalized efforts to maximize the total output of the present collider run (called Run II) over the

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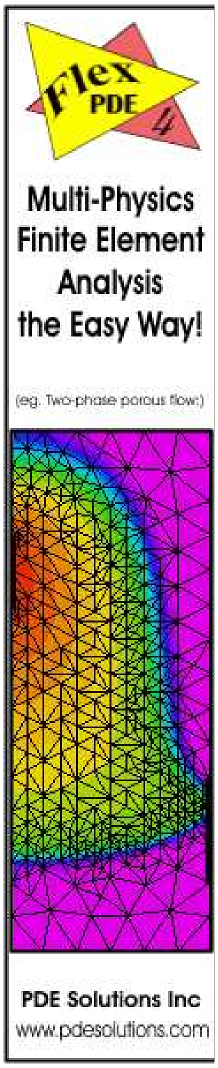

period 2001-09. To that end, two major Fermilab undertakings, both already well into the R&D phase, have now been canceled.

At the 29 September meeting of HEPAP, the High Energy Physics Advisory Panel to the Department of Energy and NSF, its P5 (Particle Physics Projects Prioritization Panel) subgroup submitted a strong recommendation that two previously approved projects should not go forward:

- the planned upgrades of the silicon components of the collider's two large detectors (CDF and D0), which would require a nine-month shutdown in 2006, and
- the CKM (Charged Kaons at the Main Injector) experiment, which was to be built in time to start studying rare kaon decays with a high-flux K^+ beam from a fixed target at the main injector when Run II ends in 2009.

Unlike the silicon upgrade, the construction of CKM had not yet received funding authorization. Its cancellation is impelled primarily by the urgent need for funds to optimize Run II. HEPAP has endorsed the recommended cancellations and forwarded them to the funding agencies. Fermilab director Michael Witherell had also concluded that the silicon upgrades should be canceled and informed the detector groups of his decision on 3 September.

These painful cancellations were dictated by a constricting budget as well as the limited time left before the LHC, with its much higher energy, threatens to preempt the discoveries--chief among them the Higgs boson and the lightest supersymmetric particles--that the Fermilab physicists would dearly love to make first.

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Time, money, and the Higgs

The Higgs would be the particle manifestation of the quantum field that is presumed to break the underlying symmetry between the weak and electromagnetic forces and give the fundamental particles their masses. Assuming the simplest Higgs physics consistent with the standard model of particle physics, one can predict the Higgs particle's mass from the mass of the top quark and other parameters. Such measurements already predict a Higgs mass of less than about 130 GeV, easily light enough to be created at the Tevatron's energy. (Searches at LEP have excluded a Higgs lighter than 115 GeV.)

But energy is not everything. Producing enough Higgs particles for a statistically robust signal depends on the collider's luminosity--that is, its event rate per unit scattering cross section--and the time integral of the luminosity over the entire run.

The Tevatron detector groups estimate that a five-standard-deviation signal of a Higgs heavier than 115 GeV will require an integrated luminosity of at least 15 fb^{-1}--that is, enough to produce a total of 15 events per femtobarn (10^{-39} cm^2) of cross section. Unfortunately, the latest projections of the total integrated luminosity for Run II by 2009 do not exceed 8 fb^{-1}, and a more conservative "base projection" of 4 fb^{-1} is regarded as less problematic. One can make a lot of important discoveries at the Tevatron with 8 fb^{-1}, or even 4. But they probably won't include finding the Higgs.

Reaching even 4 fb^{-1} by 2009 will require a succession of accelerator upgrades with as little downtime as possible. The long shutdown for the silicon detector upgrades and the inevitable recommissioning time would have cost about a year that the Run II schedule could ill afford. Add to that the roughly $20 million that will be freed up for accelerator maintenance and upgrades in a very tight budget, and one might think the silicon cancellation was an easy decision.

But it wasn't. Arrays of silicon microstrips in the innermost precincts of the two detectors record, with 20-μm resolution, the decay vertices of very short-lived B mesons created in the p-p+ collisions. Finding B decays is crucial for the identification of top quarks. And a very high priority of Run II is precision measurement of the mass and other properties of the top quark.

The silicon detector elements are gradually degraded by radiation damage from the intense barrage of p-p+ collision products. For a long time, one can compensate for that damage by cranking up the biasing voltages on the silicon heterostructures. But eventually, after an integrated luminosity of perhaps 4 or 6 fb^{-1}, the detectors have to be taken apart and the innermost silicon replaced if one wants to keep tagging B mesons efficiently. That's why a nine-month shutdown was originally scheduled for the middle of Run II.

As estimates of Run II's integrated luminosity have retreated since 2001, from an exuberant 15 fb^{-1} to half that value or less, the rationale for a silicon upgrade that's costly in time and money has weakened. The important physics that requires tagging B decays would suffer once the silicon is damaged beyond remedy. But there's lots of other physics that doesn't need the 20-μm resolution. And it's no longer clear that the innermost silicon will reach the breaking point before the end of Run II.

"Funding for Fermilab and high-energy physics in recent years has not kept up with inflation," says Witherell. "I made the difficult decision to cancel the silicon upgrades because I believe it will let Run II achieve the most science within the limits of our budget and the remaining time." The cancellation is particularly hard on younger physicists in the CDF and D0 collaborations who devoted the past few years to the silicon upgrades.

The other painful choice

The P5 recommendation that CKM not go forward was more purely budgetary. "The CKM collaboration has designed an elegant, world-class experiment that would produce important physics, says P5 chair Abraham Seiden (University of California, Santa Cruz). By measuring an ultrarare kaon decay, the experiment would provide an extraordinarily sensitive probe for new physics beyond the standard model.

There is another experiment, called BTeV, which was also intended to start taking data as soon as Run II ends. The BTeV collaboration proposes to build a novel spectrometer that would exploit the Tevatron's prolific production of B mesons to look for signs of new physics in B decay. The LHC's higher energy is no great advantage for that kind of B physics, and P5 judges BTeV to be at least as promising as LHCb, the rival facility under construction at CERN.

CKM and BTeV would each cost roughly $100 million to build and, starting in 2009, they could run simultaneously. That was Fermilab's plan, but the P5 report judged it "too ambitious," given budgetary constraints and the need to get the most out of Run II. Finding that "BTeV has a much broader physics program," P5 regretfully recommended canceling CKM, and proceeding expeditiously with BTeV. During and after Run II, fixed targets at the main injector would also sustain a rich program of neutrino experiments.

Tougher than anticipated

In July, a DOE committee headed by Daniel Lehman had reviewed the progress and prospects of Fermilab's plan for upgrading the Run II luminosity. They concluded that achieving 8 fb^{-1} depended crucially on the successful implementation of electron cooling in the collider's new antiproton recycler. That challenging task, they stated, presents "a very significant uncertainty."

Antiprotons are the collider's scarcest commodity. The recycler is an 8-GeV storage ring built during the 1996-2001 shutdown. Its original purpose was to salvage and reinject antiprotons from beams that had become depleted and ragged after circulating for hours in the collider. That goal, which requires decelerating the TeV antiproton beam to 8 GeV, proved difficult. It was then decided that more could be gained by giving the recycler the less demanding task, still to be implemented, of increasing the machine's storage capacity for antiprotons before they are sent to the main injector.

The lower the emittance (phase-space spread) of the antiproton beam, the higher will be the collider's luminosity. To minimize emittance, the plan is to bring the antiproton beam in the recycler into contact with a low-emittance electron beam. This kind of "electron cooling," a well-known technique at much lower energies, has never before been attempted at anything like 8 GeV.

The recycler's primary problem has been maintaining the requisite ultrahigh vacuum for the hours-long storage of antiprotons throughout its 3-km circumference. Another problem has been the decision to use only permanent magnets, rather than electromagnets, in the recycler, which makes it the largest permanent-magnet ring ever built. The choice was made to minimize cost and complexity. But it turns out that tuning the beam in the recycler is difficult when one doesn't have magnet currents to play with.

The Tevatron collider is, by far, the most complex accelerator ever to reach the operation stage. Its great success in the early 1990s was part of the problem, suggests a sympathetic observer. "The Fermilab accelerator people were so far ahead of everyone else in energy and luminosity, they thought they could do anything. But here, at the frontier of several technologies, some things turned out to be tougher than they anticipated. And then they were slow to call on expert help from other parts of the lab and from outside Fermilab."

In response to these and other criticisms, widely heard, of Fermilab's management of the accelerator work, Witherell has reorganized the lab's beams division to facilitate interaction with other parts of the laboratory and to involve himself more directly in the Run II luminosity upgrade. Beam monitoring instrumentation is also being enhanced throughout the accelerator complex. The Lehman committee's July review, while applauding the reorganization and improved instrumentation, reached the unusually tentative conclusion that it was "too early to tell if the [luminosity upgrade] plan is realistic." The committee will review the upgrade again early in 2004.

To some extent, the vexing luminosity issue stems from heightened, perhaps unrealistic, expectations. A decade ago, when the predicted mass of the Higgs was closer to 1 TeV, there was little hope of finding it at the Tevatron. But as the prediction has come down to a much more accessible range near 100 GeV, Fermilab has come under intense--some say unreasonable--pressure to raise the collider's luminosity enough to find the Higgs before the LHC.

Even if an integrated luminosity of 4 fb^{-1} is not enough to give clear evidence of the expected "light" Higgs, it probably would suffice to exclude, at the 95% confidence level, a Higgs particle lighter than 130 GeV. Such a nondiscovery would be of particular interest if Fermilab's precision measurement of the top-quark mass points to a Higgs mass unambiguously below 130 GeV. It would tell us that nature has chosen something more subtle than the minimal standard-model Higgs mechanism.

Witherell, who has been Fermilab's director since July 1999, announced on 3 October that he will retire from that post at the end of June 2005.

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