Fermilab's path to the future

by Elizabeth Clements

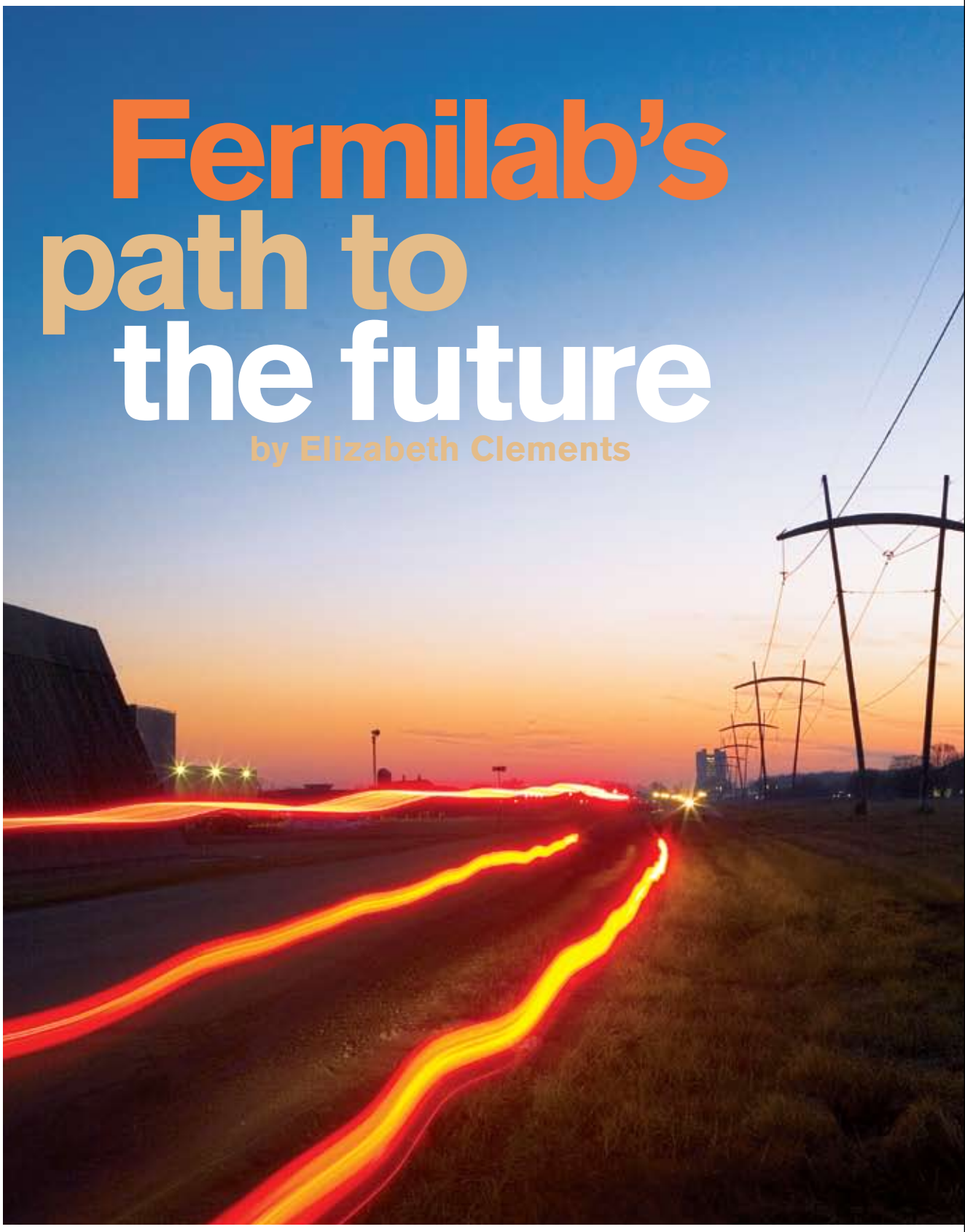
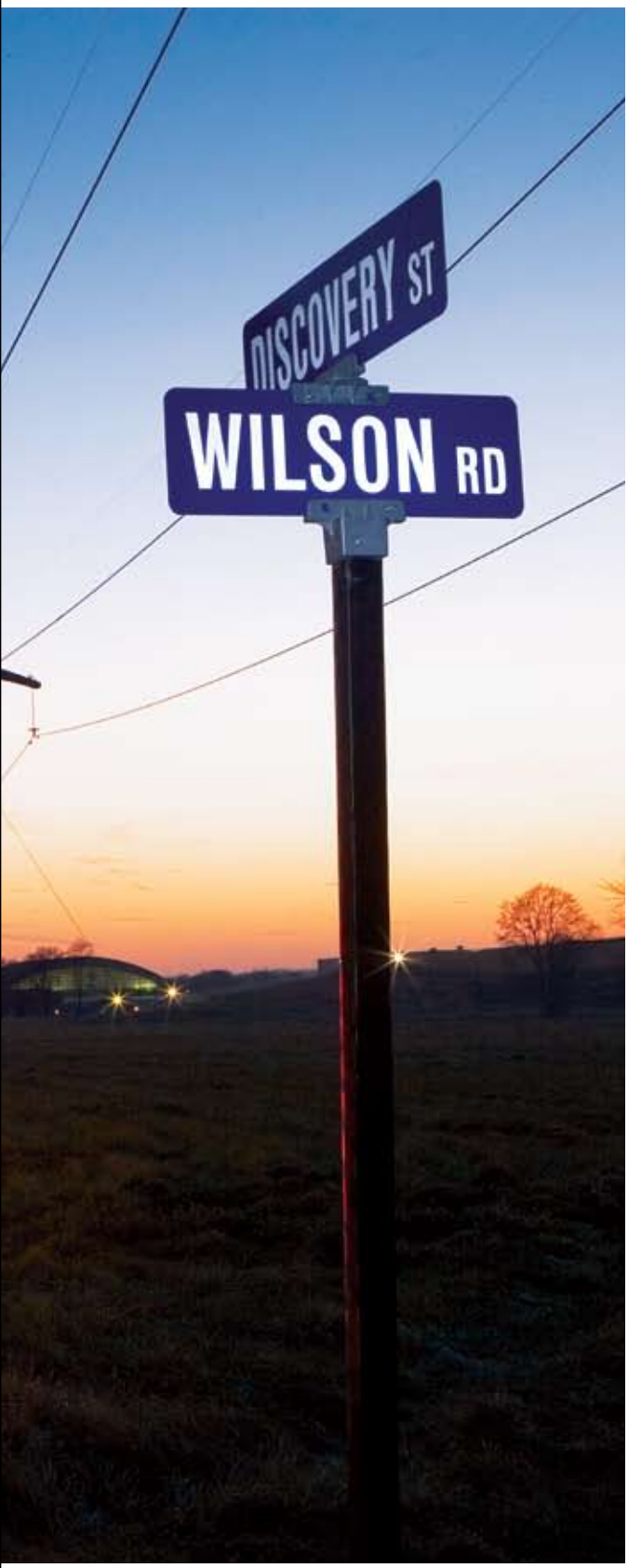


Photo: Fred Ullrich, Fermilab

A new report gives top priority to developing the International Linear Collider, while laying out a plan for science that could be done along the way.



Fermi National Accelerator Laboratory in Batavia, Illinois is home to the Tevatron, the highest-energy particle accelerator in the world. But in 2008, the Large Hadron Collider, a proton-proton accelerator with seven times as much energy, will turn on in Geneva, Switzerland and become the center of particle physics research for years to come. By the end of this decade, the Tevatron will shut down, although its world-leading neutrino program will continue. This leaves the lab with a challenge: how will it maintain its central role as a place where particle accelerators produce groundbreaking discoveries in physics?

Any answer must be compatible with the goals of the global particle physics community, which has determined that the next big project should be the International Linear Collider, a 31-kilometer-long accelerator that will smash together electrons and their antimatter opposites, positrons. An international team of scientists has laid out a technically driven timeline in which construction would start in 2012 and take seven years. However, the multi-billion-dollar project will require international management and funding, and getting things organized could take some time.

In February 2007, Raymond Orbach, Under Secretary for Science for the US Department of Energy, raised the possibility that the ILC might take longer to build than the physics community had hoped. Speaking at a meeting of the High Energy Physics Advisory Panel, he asked the US particle physics community to "re-engage" in a discussion of the future of particle physics. If the ILC does not turn on until the middle or end of the 2020s, Orbach asked, "What are the right investment choices to ensure the vitality and continuity of the field during the next two to three decades, and to maximize the potential for major discovery during that period?"

In response to Orbach's request, Fermilab Director Pier Oddone appointed a steering group to propose a plan for the future of the lab. The plan, Oddone said, should support research and development for the earliest possible start of the ILC, while at the same time proposing options in case it's delayed. He also asked the group to recommend steps toward even higher-energy colliders than the ILC, in case results from Europe's Large Hadron Collider indicate a need for those higher energies.

The steering group, led by deputy lab director Young-Kee Kim and composed of particle physicists and accelerator scientists from across the nation, convened in late March. Kim held meetings and town-hall sessions at laboratories and experiments from coast to coast, asked for input from the particle physics community, and opened the group's meetings to anyone who had an interest. Responses included 17 expressions of interest and several letters. The group found strong community support for the idea that a US laboratory should maintain a strong accelerator-based program of particle physics.

After just four months of intense discussions, focused study and vigorous debate, the steering group concurred on a plan.

Priorities confirmed

The plan reiterates that the LHC and the ILC are Fermilab's top priorities. That's where the physics of the Terascale—a term that describes particle collisions with energies measured in trillions of electronvolts—will be discovered. So Fermilab should continue to participate in the LHC and play a leading role in the effort to make the ILC a reality as soon as possible. In fact, the lab's goal is to host the ILC, and it has already been meeting with local residents to discuss the possibility of building the collider there.

If the ILC is delayed by a couple of years, the group recommends that Fermilab develop a more intense proton source for its current neutrino program, using the existing accelerator complex. This project would be called Super NuMI, or SNuMI.

Should the ILC timeline stretch even more, the group calls for building a new facility, called Project X for the time being. Project X would combine a new linear accelerator with the lab's existing accelerators to generate high-intensity beams of protons for experiments that address fundamental questions:

Are there undiscovered principles of nature? New symmetries, new physical laws?

Do all the forces become one?

How did the universe come to be?

What are neutrinos telling us?

What happened to the antimatter?

If the global community decides to build the ILC outside the US, the group proposes that Fermilab pursue SNuMI or, alternatively, Project X, if resources and timing permit.

The group stops short of suggesting that Fermilab seek formal approval of Project X. But it recommends starting the initial research and development now, in a way that will also expedite development of the ILC and the industrial base needed to build it. Oddone estimates that this R&D will cost about $50 million, take a few years, and require the equivalent of 30 to 40 full-time employees spread across various labs and universities. With this level of effort, an engineering design could be ready by the end of the decade, at which point the physics community would know enough about progress on the ILC to decide whether or not to proceed with an interim plan.

Project X

The proposed Project X is a linear accelerator 700 meters long—roughly the length of seven football fields—that would be constructed in the center of the Tevatron ring. With 8 billion electron volts (GeV) of energy, it would generate an intense beam of protons that feed into an existing accelerator ring and then into the lab's Main Injector.

The core technology for Project X is almost identical to that for the ILC; in fact, it would operate as a sort of mini-ILC, one-hundredth the length of the real thing. Both would use cryomodules—vessels that contain niobium cavities, cooled to near-absolute zero—to accelerate particles, although Project X would accelerate protons and the ILC electrons. Project X would require about 36 cryomodules;

the ILC calls for about 2000. Steering group members say Project X could help test the design for the ILC and establish an industrial base in the US for building its components.

The report concludes that the engineering required to build Project X would advance research and development for the ILC. Project X could also accelerate electrons, if necessary, for specific ILC-related studies, says Fermilab accelerator physicist David McGinnis.

Project X would train highly skilled technicians and engineers needed to build the ILC. Maury Tigner, an ILC physicist at Cornell University who served on the steering group, says that if Project X trains people and keeps the ILC program going, that's a good alignment between the two.

In addition to building a new linear accelerator, Project X would require a number of modifications to one of Fermilab's rings and its Main Injector. Although any cost estimate made without an engineering design is extremely rough, the group expects Project X would cost on the order of $500 million in today's dollars, about 10 percent of which would be spent over the next two years for research and development.

The intensity frontier

Both the LHC and the proposed ILC will smash particles together at much higher energies than ever achieved before, creating particles that could not have been observed in earlier machines. This approach to finding new physics is known as the energy frontier.

Project X would explore a different arena known as the intensity frontier: Rather than pour more energy into the particles it generates, it would generate more particles, and thus a more intense beam—10 times more intense than those used in today's neutrino experiments. This would open a pathway to discovery in neutrino science and in an area known as precision physics.

Neutrinos are among the most mysterious particles in the universe. Every second of our lives, trillions of them stream through our bodies; but since they barely interact with other forms of matter, we take no notice. The sun

Photo: Fred Ullrich, Fermilab

Fermilab Steering Group's proposed plan

The Steering Group recommends the following plan for the accelerator-based particle physics program at Fermilab.

- Fermilab's highest priority is discovering the physics of the Terascale by participating in the LHC, being one of the leaders in the global ILC effort, and striving to make the ILC at Fermilab a reality.
- Fermilab will continue its neutrino program with NOvA as a flagship experiment through the middle of the next decade.

- If the ILC remains near the timeline proposed by the Global Design Effort, Fermilab will focus on the above programs.
- If the ILC departs from the GDE-proposed timeline, in addition Fermilab should pursue neutrino-science and precision-physics opportunities by upgrading the proton accelerator complex.
  - If the ILC start must wait for a couple of years, the laboratory should undertake the SNuMI project.
  - If the ILC postponement would accommodate an interim major project, the laboratory should undertake Project X for its science capability and ILC alignment.

- If the ILC is constructed offshore, in addition Fermilab should pursue neutrino-science and precision-physics opportunities by upgrading current proton facilities while supporting the ILC as the highest priority.
  - The laboratory should undertake SNuMI at a minimum.
  - Alternatively, the laboratory should undertake Project X if resources are available and ILC timing permits.

- In all scenarios,
  - R&D support for Project X should be started now, with emphasis on
    - expediting R&D and industrialization of ILC cavities and cryomodules,
    - overall design of Project X.
  - R&D for future accelerator options concentrating on a neutrino factory and a muon collider should be increased.
  - The laboratory should support detector R&D and test-beam efforts for effective use of future facilities.

Recommendations taken from Fermilab Steering Group Report*, 2007*

Project X schematic

Project X would connect an ILC-like linear accelerator to Fermilab's existing Main Injector and Recycler rings to produce high-intensity proton beams.

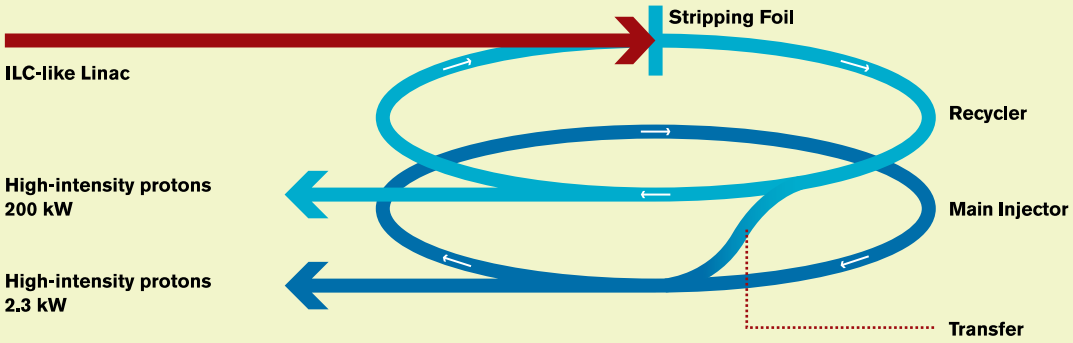


Photo: Cindy Arnold, Fermilab

is a rich source of neutrinos, and the source of another puzzle: Although only one type of neutrino emerges from the sun, it can morph into two other types during its journey to Earth. The neutrino is also at the heart of a theory called "leptogenesis"—the idea that all visible matter comes from neutrinos. If this theory is correct, the report says, "we owe our existence to neutrinos from the big bang."

Project X could shed light on leptogenesis and illuminate the ordering, or hierarchy, of the three neutrino types, with their three slightly different masses. This information is key to understanding the role of the neutrino in unification—the idea that all the forces and particles might, at some fundamental level, merge into one.

Fermilab's accelerators already generate a beam of neutrinos that travel 735 kilometers underground to a detector in Minnesota's Soudan Mine. In the future, the lab might also provide neutrinos to detectors in the proposed Deep Underground Science and Engineering Laboratory, located in South Dakota's Homestake Mine.

Another project under way at Fermilab, called NOνA, calls for upgrading the existing accelerator and building two new neutrino detectors—one on site and the other 810 kilometers away, at Ash River near the Canadian border. This experiment would look for evidence that muon neutrinos are changing into electron neutrinos, says John Cooper, the Fermilab project manager. It's under review at the Department of Energy, and could start operating in 2011.

Project X would greatly increase the intensity of the beams available for these experiments.

It would also provide particle beams for a new generation of precision experiments. These are experiments that try to detect the nearly invisible footprints of very-high-energy phenomena by observing their effects on processes at lower energies.

The discovery that one kind of neutrino can convert into another—known as "flavor violation"—has led physicists to ask whether this also occurs in the charged leptons, the electron, muon and tau. Several theoretical models predict that such conversions should happen.

Project X could produce large numbers of muons for experiments that look for muon-to-electron conversions with 10,000 times more sensitivity than before. Combined with results from neutrino experiments and from the LHC, these experiments might provide support for leptogenesis or unification.

Project X could also generate beams of kaons that are incredibly pure and intense, allowing experiments that look for rare decays of these particles. These decays offer a unique way to probe why matter came to predominate over antimatter in the universe.

Sally Dawson, a physicist at Brookhaven National Laboratory, served on the EPP2010 National Academy panel whose 2005 report recommended priorities for US particle physics; she was also a member of the Fermilab steering group. She says she believes the physics goals of Project X fit into the panel's priorities, and could potentially complement the discovery possibilities of the LHC and ILC.

University of Chicago physicist Mel Shochet, who chairs the High Energy Physics Advisory Panel to the Department of Energy and the National Science Foundation, also participated in meetings of the steering group. He says results from the LHC may be available by 2010, the point at which a decision to build Project X would be made. Depending on the results from the LHC, he says, Project X could become a high priority for the scientific community.

Another steering group member, Tom Himel, an ILC leader at the Stanford Linear Accelerator Center, says he hopes the ILC will be built as soon as possible, making Project X unnecessary. However, he says it would be irresponsible for Fermilab not to propose an interim plan in case of a delay.

What's next

Before its formal presentation to funding agencies, the report will make its way through the US particle physics advisory system—Fermilab's Physics Advisory Committee, the Particle Physics Project Prioritization Panel, and HEPAP.

Kim says Fermilab's Accelerator Advisory Committee gave the steering group's plan strong support. While the committee appreciated the broad scope of the plan, it endorsed Fermilab's effort to make clear that ILC, not Project X, is the lab's top priority.

Fermilab Director Pier Oddone says he remains determined to build the ILC as soon as possible. He says he's confident the proposed plan provides the flexibility that Fermilab needs to remain a leader in the world particle physics community, no matter how events unfold, and his next objective is to secure funding for Project X research and development.

If the US particle physics community endorses Fermilab's proposed plan and the Department of Energy funds it, R&D on Project X could start in late 2008, keeping Fermilab on the pathway to discovery.

Photo: Reidar Hahn, Fermilab

Fermilab Deputy Director Young-Kee Kim, far left, chaired the Steering Group charged to propose a plan for Fermilab's future in the event of a delayed ILC. Open meetings like the one held at Fermilab on June 12 involved many particle physicists.