No Little Plans

Fermilab's Future in 21st-Century Particle Physics

by Mike Perricone

Pier Oddone outlines the future of Fermilab during a presentation to the Elementary Particle Physics in the 21st Century committee.

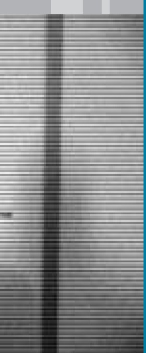
Photos: Reidar Hahn, Fermilab

In his vision for Fermilab's future, director Pier Oddone offers insight from a bumper sticker: "If you want to predict the future, help create it."

Oddone makes his outlook still clearer by quoting Daniel Burnham. "Make no little plans; they have no magic to stir men's blood," said Burnham, the famed architect whose design of the 1893 Columbian Exposition transformed Chicago into a world city.

"When Burnham built the Columbian Exposition," Oddone said recently, "the world came to Chicago. When we build the International Linear Collider at Fermilab, the world will come here."

With the world joining in, Oddone envisions discoveries that add up to a revolution in particle physics. "This is the best, the most exciting time ever for particle physics research. I am convinced that's the case. During my lifetime, I cannot remember a time of greater promise for our field," says Oddone, who began his appointment as Fermilab's fifth director on July 1, 2005.



Questions for the universe

The promise and challenge of 21st-century particle physics and the future of Fermilab are one and the same. Like Copernicus' recognition in 1530 that the Earth revolves around the sun and not the other way around, the recent discovery that only five percent of the universe is made of familiar, visible matter has profoundly shifted scientists' views of the physics of matter, energy, space and time. The recognition that most of the world around us is a *terra incognita* of dark matter and dark energy has led physicists to formulate a set of questions that will profoundly change the science of particle physics—and define the future of Fermilab in the decades ahead.

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

Are there extra dimensions of space?

Do all of nature's forces become one?

Why are there so many kinds of particles?

What is dark matter?

What are neutrinos telling us?

Particle demographics

If scientific revolution weren't excitement enough, the changing global demographics of particle accelerator laboratories in the United States and abroad put the spotlight on Fermilab's role in creating the future of particle physics. With California's SLAC, Japan's KEK and Germany's DESY laboratories making the transition from particle physics to light-source-based research, Fermilab will assume major responsibility, along with CERN in Europe, for leadership of the world's particle physics community. Fermilab is set to become the single major accelerator-based particle physics laboratory in the United States.

Addressing a Fermilab audience in early April 2005, Robin Staffin, associate director for High Energy Physics in the Department of Energy's Office of Science, told listeners that the laboratory "will play a central and critical role for US particle physics, both here and abroad." He described the Fermilab and US high-energy physics programs as "inextricably linked," meaning they would now be virtually one and the same.

To Oddone, the identity is a logical extension of Fermilab's traditional role. "From its inception," he says, "this has been the people's lab, the community's lab. Fermilab has always exploited its machines through very strong connections with the rest of the community."

In the context of this new scientific landscape, Oddone recently defined his vision for Fermilab's future for a National Academy of Sciences panel on Elementary Particle Physics in the 21st Century (EPP2010), with members from both within and outside the field of particle physics. The panel's report, due in December 2005, will provide the basis for a 15-year plan for the field. Fermilab's goals, Oddone told the panel, are to enable the most powerful exploration of the fundamental questions of particle physics; to provide world-class facilities for particle physics as part of the global community; and to develop science and technology for the next generation of particle physics and cosmology research. Specifically, in the next decade Fermilab will work to develop a major facility at the energy frontier and to sustain the world's foremost neutrino program.

The highest priority

When the Large Hadron Collider begins operating at CERN a few years hence, the energy frontier, historic hunting ground for discovery, will move from Fermilab's Tevatron to the LHC. Will US particle physics regain

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Robin Staffin, DOE Office of Science

the high ground? The answer, many believe, lies with the International Linear Collider, a proposed international electron-positron accelerator. Physicists anticipate that, together, the LHC and the ILC would provide unprecedented capability for discovery.

Fermilab's highest priority, Oddone says, is to lead the effort to position the United States to host the ILC at Fermilab and to play major roles in ILC detector development and physics analysis. By the end of 2006, the newly-organized Global Design Effort for the ILC, headed by GDE director Barry Barish, will complete a Conceptual Design Report that will indicate whether a decision by the end of the decade on the feasibility of building the ILC appears likely. If so, Fermilab will work in collaboration with US and global partners to establish the ILC's technical design components, costs, design, and management structures to permit the global community to decide by 2010 whether to go forward with the new collider. Results from the LHC at about the same time will also inform the decision.

The LHC, followed by the proposed ILC, would break through to a new energy scale where physicists expect to make extraordinary discoveries. Few of these discoveries would come from either one or the other of these accelerators alone, most physicists believe. Together, they say, experiments at the LHC and the ILC have the potential to discover new forces of nature, find extra dimensions of space, solve the mystery of matter's domination over antimatter, discover dark matter, and fulfill Einstein's dream of uniting gravity with the other forces of nature.

“In order to build a linear collider in the United States,” says Associate Director for Accelerators Stephen Holmes, “we need to establish world-class expertise in the superconducting technology at the heart of the ILC's design. Fermilab has the scientific and engineering capabilities and building infrastructure to lead a national effort. In coordination with the GDE, we are developing facilities to assemble and test prototype ILC accelerating structures, in collaboration with national and international partners.”

If the Conceptual Design Report for the linear collider were to show the need for years of R&D before ILC construction could begin, or if the LHC failed to produce the anticipated scientific results, a decision on the ILC would be put off well beyond 2010. In such a case, Fermilab would direct its efforts toward continued development of its world–class program of neutrino research.

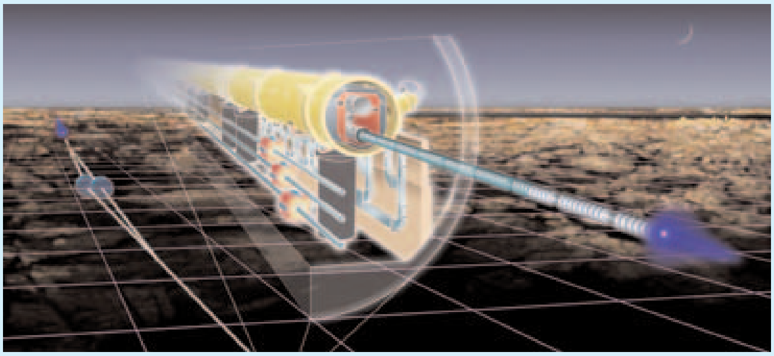


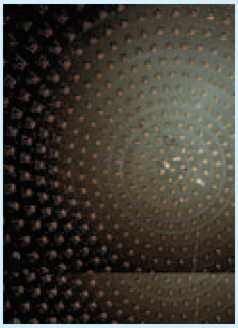
Illustration: Juna Kurihara

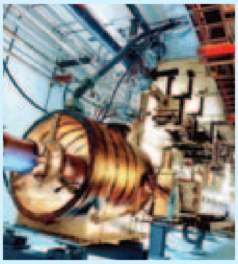
Artist's rendition of a future International Linear Collider.

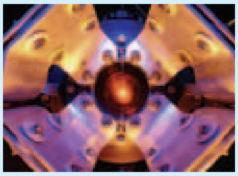
The plan for Fermilab's future…requires focusing on a few key research areas, rather than trying to do everything.

Neutrinos

In March 2005, Fermilab launched the long-baseline MINOS experiment, using the NuMI neutrino beam from Fermilab to send high-intensity neutrinos to a detector in northern Minnesota. Currently, NuMI's 200 kilowatts make it the most powerful neutrino beam in the world; upgrades would yield a 440 kW beam by 2008. When Tevatron operations cease later in the decade, NuMI's power would rise to more than 600 kW, the level that the Japanese neutrino facility J-PARC would achieve sometime after 2010. Further beam improvements could yield up to two megawatts of power.







Meanwhile, Fermilab's short-baseline MiniBooNE experiment to investigate the existence of a possible fourth species of neutrino, in addition to the known three, plans to announce its first results in fall 2005.

"All hell will break loose if they have a positive signal," Oddone says.

Recently, physicists have proposed another Fermilab long-baseline experiment, NOνA. It would start operation around 2010, with a detector sited 80 km north of the MINOS site. The MINOS experiment looks at the disappearance of muon neutrinos; NOνA would search for electron neutrino appearance, using the existing NuMI neutrino beam to probe fundamental aspects of the mysteries of neutrino behavior.

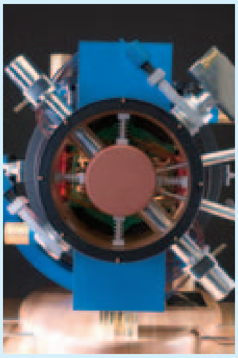
Later, a new Fermilab accelerator, a proton driver, could push neutrino research still further by providing ultra-intense neutrino "superbeams" for NOνA or another detector.

"In the near term, there is a strong synergy between the R&D for a proton driver and for the ILC," says Technical Division head Robert Kephart. "Both require developing a US infrastructure for superconducting accelerating structures. A proton driver project could promote US industrialization of this technology, which could reduce costs and technical risks for the ILC, especially if ILC construction is delayed. While the main motivation for a proton driver is neutrino science at Fermilab, it could also serve as a stepping stone to the ILC."

A hard-driving neutrino program would follow the recommendations of *The Neutrino Matrix,* a 2005 report on the future of neutrino physics by the American Physical Society Multi-Divisional Neutrino Study, supported by DOE's Office of Science and by the National Science Foundation. The report recommends a comprehensive US program on neutrino mixing, the neutrino mass spectrum and matter-antimatter asymmetry among neutrinos–the very course charted by Fermilab's neutrino program, with MINOS, MiniBooNE and the proposed NOνA.

Meanwhile…

As Fermilab pushes forward on R&D for the ILC and neutrino science, the laboratory must also deliver the maximum scientific returns from the CDF and DZero experiments at the Tevatron; prepare to exploit the enormous promise of the Large Hadron Collider and the Compact Muon Solenoid (CMS) experiment at CERN; and carry out the MINOS and MiniBooNE neutrino experiments–all while maintaining scientific vitality with a program including particle astrophysics, theory, computing, and the development of technology for the research of the future.

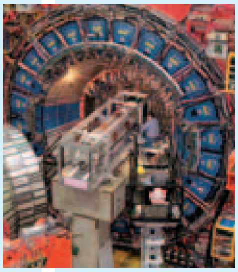


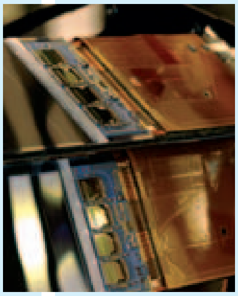
"Until the LHC experiments report their first results late in this decade," says DZero cospokesperson Gerald Blazey of Northern Illinois University, "the Tevatron will keep particle physics at the energy frontier. This continues to hold the interest of the CDF and DZero collaborations, which together have about 1500 collaborators from universities and laboratories worldwide.

As Run II luminosity continues to accelerate, CDF and DZero will close in on the Higgs boson, either finding evidence for the Higgs if it is light enough, or severely constraining its mass through precision measurements of the top quark and *W* boson. We will press the search for evidence of supersymmetry and extra dimensions and attack the problem of matter-antimatter asymmetry. The Tevatron continues to represent a very promising physics program."

Their success depends on continuing to push the Tevatron accelerator complex to its utmost capability.

"Run II science depends critically on luminosity–on how many trillions of high-energy particle collisions the Tevatron can deliver between now and 2009," says Accelerator Division head Roger Dixon. "We will lose no opportunity to maximize luminosity at every turn."





Fermilab and the Large Hadron Collider

When the LHC begins operating at CERN, it will take particle physics to a new level of energy–seven times that of the Tevatron. The Fermilab-led collaboration with DOE's Brookhaven and Berkeley labs has succeeded in delivering next-generation superconducting quadrupole magnets and other LHC components. Now, as LHC start-up approaches, Fermilab will have more key roles to play.

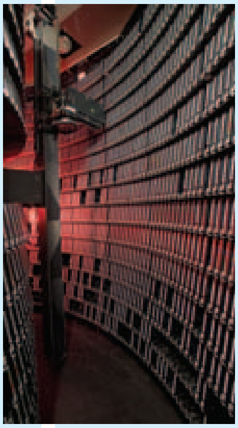
Accelerator scientists from Fermilab will bring their hard-won expertise in operating a hadron collider to support LHC commissioning. Fermilab, Brookhaven, Berkeley Lab, and SLAC have collaboratively formed the LHC Accelerator Research Program, LARP, to help develop the technology for an LHC luminosity upgrade in about 2015.

Fermilab has led the US CMS collaboration in the successful design and construction of the muon detection system and the hadron calorimeter for the CMS detector, one of two gargantuan LHC collider detectors headed for completion in 2007. The US CMS collaboration now numbers about 400 physicists from 41 institutions; its numbers will grow.

"As the only major US lab associated with CMS, Fermilab will have a central support role for the US particle physics community when the huge data and physics analysis challenge begins," says US CMS Research Program manager Dan Green. "Fermilab has established the LHC Physics Center on Wilson Hall's 11th floor to provide technical support and a critical mass of scientists, so that being at Fermilab will be 'as good as' being at CERN."

Fermilab has another vital role in CMS operations.

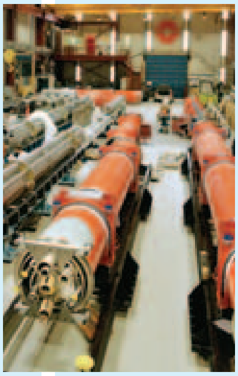
"As a Tier One computing center for LHC physics data," says Computing Division head Vicky White, "Fermilab will lead the collaborative project of delivering the deluge of data from CMS to laboratories and universities for physics analysis. Fermilab is also a leader in developing the Open Science Grid, the grid computing system that will connect US physicists with LHC data for discovery at the energy frontier."



Focus

The plan for Fermilab's future, designed to support a vital US role in global particle physics, requires focusing on a few key research areas, rather than trying to do everything. It requires the sacrifice of promising experiments and projects, including the BTeV experiment, canceled earlier this year, and other innovative explorations of quark flavor physics. However, says Oddone, it establishes the trunk and branches for the long-term growth of a research program of breadth and texture.

"I'm sure that by 2015, all our questions will not be answered," Oddone says. "The high-energy physics community will need a lab to attack the biggest questions with experiments and machines, and we'll be there to do it with them."



Photos: Fermilab and Peter Ginter