The Energy Frontier at Fermilab

*The Tevatron Collider*

The Tevatron experiments, CDF and D0, stop taking data at the end of 2011. They will then focus their efforts on publishing an array of legacy measurements utilizing the full Run II data set. Of particular importance will be the final Tevatron result on the search for the standard-model Higgs boson, which should be sensitive at the 95% CL exclusion level or better over the mass range 110-180 GeV. At masses below about 140 GeV, search channels using the  decay mode contribute significantly to the Tevatron’s sensitivity. This is the dominant decay mode at low masses and will offer complementary information relative to the LHC searches, which rely for now onor  decays in the same mass region.

CDF and D0 will also pursue other results with high priority including measurements of top-quark properties, precision measurement of the top-quark mass, measurements of diboson cross sections and kinematic distributions, search for flavor-changing neutral-current decays of heavy flavor mesons, and measurements of CP asymmetries in B-meson decays. It is expected that most of these analyses will be finished within about a year of final data taking. Some measurements, such as a precision determination of the W-boson mass using the full Run II data set, are expected to take a few additional years to complete. Since the Tevatron has a CP symmetric initial state, it offers some unique capabilities in top-quark physics and in heavy flavor samples collected by the CDF SVT trigger. The Tevatron experiments each expect to publish an additional 40 to 50 peer-reviewed journal articles beyond 2011.

*The Compact Muon Solenoid at CERN’s Large Hadron Collider*

The Fermilab CMS group will continue to exploit the very successful startup of the LHC, fulfill several major physics research goals, and prepare the CMS experiment for future operations at higher beam energies and luminosities. With over 2 fb-1 recorded at collision energies of 7 TeV, and with at least five times more data expected by the end of 2012, the CMS experiment is poised to conclusively test the standard model and to search for indications of physics beyond the standard model. The Fermilab group is directly pursuing several goals, including discovery or exclusion of the standard-model Higgs boson for any allowed mass, searches for supersymmetry well above the TeV mass scale and searches for new dijet resonances or quark compositeness up to several TeV in mass.

The group will also fulfill its essential operational responsibilities to the experiment for the duration of the 2010–2012 run, including operating, maintaining, and improving components of the CMS detector; providing a large part of the computing services to the experiment; monitoring data quality via the Remote Operations Center at Fermilab, and hosting the LHC Physics Center (LPC). Fermilab will continue to be a world-leading analysis center, providing office space, computing resources, software support, and US CMS administrative services to an expanding population of users and visitors, as well as hosting numerous schools, seminars, and workshops.

The current LHC run plan is to conclude 7-TeV collisions at the end of 2012, and then shut down for eighteen months for accelerator upgrades, which will allow for 14-TeV collisions in 2014. Taking advantage of Fermilab's experience in detector construction and microelectronics, we are directly involved in CMS upgrades for operation at higher luminosities and 14-TeV running. Planned activities include instrumenting the outer hadron calorimeter with silicon-based photomultipliers (SiPM) and extensive retooling in software and computing. Fermilab is also heavily involved in CMS upgrades to be deployed in later periods, particularly a new pixel detector and SiPM instrumentation throughout the hadron calorimeter and a new silicon tracker.

*Computing Support for Collider Experiments*

The Fermilab Scientific Computing Division stewards the petabytes of data collected by the CDF and D0 experiments and a significant fraction of the multi-petabyte datasets from the CMS experiment. Because the life cycle of these experiments extends over several decades, data preservation to enable a variety of future physics analyses is an important challenge. Data processing and analysis is done using the Fermilab computing facilities in concert with computing centers around the world connected through grid technologies. Fermilab is a founding member of the Open Science Grid (OSG) and a collaborator on the Worldwide LHC Computing Grid (WLCG). The distributed computing enabled by these consortia is essential for providing computing for simulations of physics processes, for processing the large distributed datasets, and for making these datasets available to the global user community.

*Lepton Collider Physics*

Over the next decade, experiments at the Large Hadron Collider will explore the Terascale and uncover the mechanism that distinguishes the weak interactions from electromagnetism. The answer might be the Higgs boson of the standard model or a more elaborate form of new physics—new forces of nature, new symmetries, new particles, or new dimensions of space. Highly sensitive experiments that study neutrino oscillations, transitions among different quark and lepton flavors, and aim to detect exquisitely rare processes will probe indirectly to the Terascale and beyond. What we discover will settle some of our most urgent questions and bring others into sharper focus. We expect that a diverse and extended experimental campaign will be needed to establish what determines the quark and lepton masses, mixings, and degree of CP violation. Fresh challenges are sure to arise. These might include teasing out the detailed nature of particle dark matter and giving a systematic account of the spectrum, dynamics, and symmetries that characterize new phenomena.

To prepare to capitalize on discoveries at the LHC and intensity-frontier experiments, Fermilab has joined in the development of linear electron colliders (notably the ILC at 500 GeV) and is exploring the feasibility of a multi-TeV muon collider. A multi-TeV lepton collider could be a very attractive complement to the LHC on the energy frontier. The Fermilab community is leading physics and detector studies to map out the physics potential of a muon collider in terms of the machine’s energy and luminosity. These studies will set benchmarks for various standard-model processes and new physics, and to understand how experiments could be carried out in the unusual environment of a muon collider

*Theoretical Physics at the Energy Frontier*

Fermilab’s strong theory group plays a critical role in supporting the national and international high-energy physics program. The group played a central part in conceiving the experimental program for the Tevatron and the Large Hadron Collider and in creating theoretical tools for the analysis of collider data, as well as developing ideas being put to experimental test. Members of Fermilab’s theory group are closely engaged in today’s experiments at the Tevatron and LHC while also assessing the scientific promise of future lepton and hadron colliders.

*Accelerator Technology for the Energy Frontier*

Fermilab has a strong program in technology development and fundamental accelerator science for future lepton colliders. Fermilab has become a world leader in the engineering and technology of superconducting radio-frequency accelerating structures and systems, such as would be required to construct the International Linear Collider. Substantial infrastructure and test facilities have been built to enable development, production, and testing of superconducting linac components and systems. Through a dedicated development activity involving national laboratories, universities, international partners and industry, all coordinated through the Global Design Effort, accelerating gradients that reach the ILC performance specification are obtained now with a greater than 50% yield, steadily increasing toward the final R&D goal of 90%. Efforts will continue, through close coordination with the national and international program, on demonstration of ILC beam quality parameters in Fermilab’s superconducting test accelerator, and continued development and refinement of processing techniques for achieving a high yield of high-gradient superconducting radio-frequency cavities in a cost-effective manner.

A multi-TeV muon collider has many potential advantages, most of which arise from the lack of synchrotron radiation emission by muons, which allows a compact circular design. These advantages include multi-pass acceleration and multi-pass collisions, which could make for a cost-effective approach to reaching high energy, and a very narrow energy spread. Fermilab leads the national Muon Accelerator Program (MAP) aimed at developing and demonstrating the concepts and critical technologies required to produce, capture, condition, accelerate, and store intense beams of muons. The goal of MAP is to deliver results that will permit the high-energy physics community to make an informed choice of the optimal path to a high-energy lepton collider following a focused five-year R&D program. Critical technologies are under study, including the demonstration of transverse cooling in the MICE experiment, the study of RF cavity performance in the presence of high magnetic fields, as is required in a muon cooling channel, and the study of very high field solenoids, together with advanced beam dynamics simulations of the production, capture, cooling, acceleration and collision processes. The initial application of these new technologies might be in a neutrino factory based on a muon storage ring.

*Magnet Technology for the Energy Frontier*

The development of high-field superconducting magnets has been central to achieving higher and higher energies in the Tevatron and Large Hadron Collider. Building on the niobium–titanium superconductor technology developed for the Tevatron, Fermilab and collaborating U.S. institutions have contributed to the construction of the LHC focusing triplets. This established technology is limited to dipole magnetic fields of 8 to 10 teslas. Recognizing this limitation, Fermilab initiated a program to develop magnets based on niobium-3–tin superconductor, with the aim of achieving dipole fields of 14 to 16 teslas. In the context of the LHC Accelerator Research Program, Fermilab (together with Brookhaven and Berkeley Lab) has achieved a major breakthrough in the construction of reliable, accelerator-quality, long niobium-3–tin magnets. bringing the technology from the R&D lab to being "production-ready" for the immediate-future LHC luminosity upgrade planned for the 2020s decade.

A future muon collider or Very Large Hadron Collider will both benefit from magnets capable of achieving the highest possible fields. For example, one design for a muon collider requires 50-tesla focusing solenoids, while a 40-TeV VLHC in the LHC tunnel would demand 25 to 30-tesla dipole fields. Such magnets could be based on high-temperature superconductors (HTS) operating at low temperatures, where they can carry high currents in high magnetic fields. Fermilab is engaged in R&D leading to the construction of the first HTS-based magnets for the future energy-frontier accelerators.