Report of the 2007 FRA Visiting Committee for Fermilab Scientific Programs

April 20-21, 2007

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1 Introduction

The Fermilab Research Alliance (FRA) Visiting Committee met at Fermilab on April 20-21, 2007 to review the Laboratory's scientific program. The charge to the Committee and the meeting agenda are provided in the Appendices. This was the first meeting of the FRA Visiting Committee, following the formation of FRA as the successor to Universities Research Association, Inc. (URA), and FRA's successful bid for the DOE contract to operate Fermilab in 2006. This year's Committee conducted its visit in much the same way as last year's URA Visiting Committee and had considerable overlap in membership, in keeping with the smooth transition that has characterized the transition from URA to FRA.

One important change in the organization of FRA is the fact that the University of Chicago is now a 50/50 partner with URA, and the FRA Board of Overseers is chaired by the University of Chicago's President, Prof. Robert Zimmer. The University of Chicago's Vice-President for Research and National Laboratories, Prof. Donald Levy was present at the closeout of this meeting, and he also met with the Committee in closed session. The Committee is pleased with the enhanced scientific partnership between Fermilab and the University of Chicago, and appreciated the opportunity to present our findings directly to Prof. Levy and to discuss the main recommendations with him.

2 Executive Summary

The general impression that emerged from our two-day meeting was that of a well-managed laboratory with an excellent portfolio of scientific experiments, an accelerator complex that is purring along, and a sound scientific strategy going forward. Fermilab teams have announced a number of exciting new scientific results in the past year, including such highlights as the first observation of oscillations in B_s mesons, the first evidence for single top production, an improved measurement of neutrino mass splitting from MINOS, and the recent unveiling of MiniBooNe's first results, which decisively rule out the anomalous neutrino mixing claimed by an earlier experiment.

The transition from URA to FRA has been smooth, and the Director deserves credit for taking the opportunity provided by the contract competition to strengthen Fermilab's relationship with the University of Chicago and other local universities. Furthermore, the Director has established a policy of dealing with problems in an open and intellectually honest manner that has increased the Laboratory's credibility and avoided potential public relations pitfalls.

That said, Fermilab still faces significant challenges. The budgetary constraints in DOE-HEP have made it increasingly difficult to start new programs, even those that survive the multi-layered and increasingly rigorous process of external peer review. NOvA, for example, has been de-scoped several times due to funding constraints, and Fermilab's efforts to become a leader in the superconducting RF technology that will be the foundation of the ILC have been hampered by lack of resources.

Another challenge is coming as the energy frontier shifts from Fermilab to CERN in the next few years. During this period, the Laboratory must maximize the luminosity for Run II, and CDF and D0 must continue their efficient operations and data analysis programs – even as many physicists begin to shift their focus to LHC. Fermilab has already completed several construction projects to provide components for CMS and LHC, and is now playing a major role in the detector and accelerator commissioning efforts. At the same time, R&D for the ILC is ramping up into a significant component of the US program, and Fermilab must become a world leader in the ILC superconducting RF technology as it prepares to be the site for the eventual US bid to host. The challenges of the coming years will require strong leadership to successfully juggle all of these important but competing programs, while keeping a sense of united purpose and maintaining good morale among the Fermilab staff.

A recurring theme during our meeting was that this is a time of transition both at Fermilab and in the entire US program. Fermilab will take on new importance as the only single-purpose high energy physics laboratory in the US, and will be the leader in the US for particle physics. Fermilab must approach this role with care, balancing its need to develop a strong in-house physics program with the need to support, rather than compete with, smaller labs and university groups. The Laboratory must be pro-active in redefining what it means to be a "Fermilab user". The definition must expand to include physicists who are working at CERN, on accelerator neutrino experiments far from the site, on astrophysics and cosmology experiments located in the southern hemisphere, and eventually perhaps even to experiments located in outer space. The symbiotic relationship between Fermilab and its users must evolve to encompass the growing variety of users, and must be cultivated to create bonds even when no on-site experiment is involved.

3 Scientific Strategy

The past year has been very busy for Fermilab management, with the formation of a new entity, the Fermilab Research Alliance (FRA) as the successor to the Universities Research Association (URA), and FRA's successful bid in the federal competition for the contract to operate Fermilab. Continuity in the top Fermilab management team has ensured a smooth transition to the terms of the new contract. Like its predecessor, FRA is a consortium of major research universities, but unlike URA, FRA has a 50% stakeholder, the University of Chicago. This is reflected in the University's increased role in FRA governance, as well as in strengthened scientific and strategic ties with Fermilab.

The FRA scientific strategy has three primary scientific fronts:

- **Energy frontier**: Run II of the Tevatron is the leading edge in this field and will continue at least through 2009, overlapping with the LHC turn on in 2008. Fermilab's strong role in the CMS experiment will ensure a continuing presence at the energy frontier during the next decade. In parallel, the Laboratory is making a significant investment in R&D towards the long-term goal of hosting the International Linear Collider.

- **Neutrino physics**: MINOS, Mini-Boone, SciBooNE and Minerva are the current and near-term experiments in this field, to be followed by NOvA which is soon to start construction. A campaign to increase the neutrino flux from the present 400 kW to 700 kW and eventually to 1.2 MW is also part of this program.
- **Particle astrophysics**: This program includes current and future experiments to study dark energy (SDSS-II, DES and JDEM), current and future searches for dark matter (CDMS, CDMS-25, COUPP) and the observation of ultra-high-energy cosmic rays (Pierre Auger)

The Committee found this three-pronged strategy to be well suited to the strengths of the Laboratory, consistent with the planning documents for the field (e.g., the National Academies' EPP 2010 report and the 2006 P5 Roadmap), and well aligned with the discovery opportunities in elementary-particle physics.

Under the terms of the new FRA contract, several new initiatives are planned to enhance Fermilab's scientific program, personnel and partnerships, including:

- Establishment of Centers for focus areas in the lab, most notably the ILC Center, the Accelerator Physics Center, the Center for Particle Astrophysics and the LHC Physics Center. *These Centers are up and running (or will be soon).*
- Joint appointments with local universities. *Policies have been established and preliminary negotiations are in progress with all the local universities who are members of FRA.*
- Partnership in Grid Computation. *Activity underway with ANL and U of Chicago.*
- International Fellows Programs; *launched.*
- Organization and Human Asset Planning. *Initial study underway.*
- Enhanced Strategic Planning.
- HEP Community Partnership.

As indicated above, significant progress has been made on most of these new FRA initiatives. The Committee noted that few details were available regarding the implementation of the HEP Community Partnership initiative, although the basic concept is worthy of further development in a broad sense. Fermilab is an important national resource, and its partners include not just regional institutions, but all HEP universities nationwide.

In response to the publication of the preliminary ILC cost estimate by the Global Design Effort (GDE) group, the DOE Undersecretary for Science, Dr. Ray Orbach raised concerns that if a construction start for the ILC is delayed into the second half of the next decade, the vitality of US particle physics and, in particular, US expertise in accelerator physics, could be weakened during the intervening period. In response to these concerns, the Laboratory has convened a steering group under the leadership of Deputy Directory Kim to provide a strategy that will maintain a robust US program in accelerator-based high-energy physics, with a compelling scientific program.

In many of the talks the Committee heard about current collaboration and cooperation with Argonne as well as plans for the future; notable examples include ILC R&D, Grid

computing, accelerator R&D, and astrophysics. We also heard from the Director and other members of the senior management team that increased cooperation and collaboration with ANL and local universities is part of Fermilab's strategic plan.

Last but not least, the Committee heard about the Lab's handling of the failure of an inner triplet quad magnet constructed at Fermilab during a pressure test at CERN. The Lab responded quickly, decisively, and openly and immediately launched a program to develop a solution. It now appears that the fix for the problem can be implemented at a reasonable cost, and without significant additional delay to the LHC commissioning schedule. The Director's strong leadership and openness have reassured the LHC, DOE, and US HEP communities, as well as averting a public relations debacle. The Director has launched two reviews to both establish the root causes of the problem and to focus on lessons learned in order to prevent future problems. The Committee commends the Director and the Laboratory on their strong response to this unfortunate incident.

Recommendation

- Further develop and implement the HEP Community Partnership initiative, with a focus on strengthening the critical relationship of the Laboratory with the broader US HEP community during this time of rapid change.

4 Collider Run II

4.1 Run II Accelerator Performance

The performance of the Tevatron in FY07 so far has been excellent, as measured by the 62% increase in peak luminosity (to 2.9 x 10^{32} /cm^2s), the 75% increase in weekly integrated luminosity (to 45 pb^{-1}/week) and the 95% increase in monthly integrated luminosity (to 167 pb^{-1}/month).. The record for antiproton stacking reached 23x10^{10}/hr. The integrated luminosity for FY07 so far (800 pb^{-1}) is larger than the total for FY06, with a few months to go before the shutdown. These performance improvements have multiple causes, including better overall machine reliability, production of more antiprotons with smaller emittance, and a longer luminosity lifetime. Increased helix separation and a reduction of beam-beam effects contributed to the improvement in store luminosity lifetime. Three component failures in FY07 were responsible for the majority of the downtime.

The Laboratory has made realistic luminosity projections on the basis of present performance and the remaining improvements that are planned, including 2nd order chromaticity correction, and a variety of small improvements, each potentially yielding a few percent increase in luminosity. Optimization of peak versus average delivered luminosity will be very important for CDF and D0 in order to minimize backgrounds.

At this time, given the present performance and projections, a total integrated luminosity of between 6 and 7.5 fb^{-1} for Run-II seems feasible. The design goal of 8 fb^{-1} would require routine antiproton stacking rates in excess of 30x10^{10}/h, which would be quite challenging.

4.2 Run II Detector Performance

Detector operations for the CDF and D0 experiments have been stable and efficient, logging ~85% of delivered beam luminosity. Both experiments have successfully implemented upgrades to cope with the increasing Tevatron luminosity, including extensive upgrades of the trigger systems and computing capabilities. Additional increases in instantaneous luminosity are expected to be difficult to handle, so the Accelerator Division is searching for ways to increase the total luminosity without raising the instantaneous luminosity. Aging of the detectors (radiation damage) is observed as expected, and is not expected to become a significant problem during the remaining years of planned operations.

Both experiments have collected data sets in excess of 2 fb^{-1}, and thanks to significant computing upgrades, the turnaround time from data collection to analysis and publication is rather short. CDF logs about 5 million events per day and reprocesses its data every 6-8 weeks. Publication-ready data are available up to February 2007. D0 needs about one week from data collection to analysis. The full data set for summer conference results will be available for analysis in early May 2007.

Last year, both collaborations completed a planning exercise to estimate the future manpower requirements for detector operations and physics analysis. This exercise, which was rather uncertain beyond 2007, indicated that they might require help in FY08-09 to take full advantage of the Run-II physics potential. The establishment of a Tevatron Collider Task Force (TTF), combined with the Laboratory's decision to mitigate these problems by increasing the number of Research Associate positions in CDF and D0, has been an effective response to this problem.

There are some indications based on more recent projections that the manpower shortage may be not as acute as foreseen a few years ago. For instance, CDF expects about 30% more FTEs in 2007 than estimated in 2005. This is attributed to a combination of the delayed turn-on of LHC, the excellent performance of the Tevatron, and the attractive physics and leadership opportunities in CDF. The situation for D0 is not quite as rosy, although sufficient manpower appears to be available to staff the detector and operations and carry out the most important physics analyses.

4.3 Run II Physics Results

It is widely expected that the exploration of the physics at the tera-scale will lead to breakthroughs in our understanding of fundamental physics. The Tevatron is offering a first glimpse into this new, exciting energy regime. Already, several new discoveries have been reported by the CDF and D0 experiments, and significant improvements over existing measurements have been made. The Committee hopes that this stream of spectacular results from Run II will continue well into the LHC era.

The past year has been a good one for CDF and D0, which has seen a strong increase in the number of publications and Ph.D. theses over previous years. Important results have been

obtained, in particular, in the areas of heavy-flavor physics, top-quark physics, electroweak gauge-boson production, and searches for exotic phenomena. Examples include:

Heavy-flavor physics:

- discovery of B_s oscillations and precise measurements of Δm_s and $|V_{td}/V_{ts}|$, with significant impact on the global analysis of the unitarity triangle
- measurement of the CP-violating phase $\delta\phi_s$ in the B_s system using $B_s \rightarrow J/\psi\phi$ decays
- discovery of new heavy baryons $\Sigma_b^{\pm}$
- interesting new upper bound on $B_s \rightarrow \mu^+\mu^-$
- CP violation studies in $B_d \rightarrow h^+h^-$ competitive with B-factories, similar studies in $B_s \rightarrow h^+h^-$ are unique (2.5σ signal for direct CP violation in $B_s \rightarrow \pi K$)

Top-quark physics:

- best top-quark mass measurement (1%)
- direct measurement of $|V_{tb}|$
- evidence for single-top production
- studies of top-quark properties with unprecedented precision

Electroweak gauge-boson production:

- best measurement of the W-boson mass (0.05%) and width (3.5%)
- studies of diboson production: WZ channel observed, with evidence for ZZ

Higgs searches:

- important constraints on the upper bound of the Higgs mass (m_H<144 GeV), solidifying the evidence for a light Higgs

Searches for exotic phenomena:

- several new limits on supersymmetry, extra dimensions, etc. exploring the mass range up to 1 TeV and exceeding constraints obtained from LEP

In several of these analyses, in particular in the top-quark studies and Higgs searches, there have been significant improvements over the past year. Larger data sets continue to advance our understanding and modeling of QCD and electro-weak processes affecting many crucial measurements.

The Committee looks forward to seeing further improvements with more data. We are impressed with the demonstration by CDF and D0 to systematically move toward the discovery of processes with smaller and smaller cross sections. Despite these impressive improvements, however, a discovery of the Standard Model Higgs boson at the Tevatron still appears a challenging task, which would require significant advances in analysis and background reduction besides steady improvements in luminosity.

Recommendations

- The Committee recommends that the Laboratory keep operations personnel focused on the goal of meeting the luminosity goals for Run II during the remaining 2.5 years of planned running.

- The Committee remains concerned about the availability of D0 and CDF manpower after 2008, and recommends continued monitoring of the situation and regular updates from the spokespersons.

- Data analysis plans beyond FY09 should be considered. The Committee believes that CDF and D0 still have strong potential for attracting excellent graduate students and postdocs during this period in order to complete the analysis of the full Run II data set.

- Maintain the focus on the analyses with the most exciting physics potential, in particular the search for a light Higgs boson and improved indirect constraints, as well as searches for new physics. In the event of a manpower shortage, prioritize the data analysis topics.

5 LHC and CMS

5.1 Accelerator Commissioning

Less than a month before this review took place, one of the inner triplet quadrupole magnets manufactured at FNAL for the LHC failed a pressure test at CERN, and the investigation revealed an engineering design flaw that will have to be repaired on all nine of the inner triplet magnets. The resolution of this problem and repair of the magnets is a high priority for both FNAL and CERN. The response of the FNAL Management to this failure has been open, prompt and at the highest level. FNAL is collaborating with CERN to provide a technical and organizational solution to the problem, as well as conducting a thorough analysis of the root causes of the event.

FNAL has completed its construction responsibilities for the LHC accelerator, with the one exception mentioned above, and is now actively participating in commissioning. FNAL did excellent work in setting up the LHC@FNAL infrastructure, which was completed on time and under budget. This facility will allow FNAL accelerator and detector physicists to participate remotely in the LHC accelerator and CMS detector commissioning activities. CERN is considering using the concept developed at FNAL for a 'remote' CMS control room in the CERN Meyrin site. The center has great potential for providing communication and training for both detector and accelerator personnel in the US collaborating with LHC.

The present plan for CMS is full remote integration with detector operations. It is a possibility that CMS shifts will be run from FNAL after an appropriately long initial phase of "read-only" operations. The present plan for remote presence of LHC accelerator commissioning does not include active access of the LHC control system, primarily because of the machine protection issues related to the LHC stored energy.

FNAL has a rather clear strategy for participation in the LHC accelerator commissioning, which is based both on the LHC Accelerator Research Program (LARP), a collaborative program involving FNAL, BNL, LBNL, and SLAC, and through unilateral initiatives with CERN to contribute FNAL expertise in the field of accelerator operations application software, leveraging on the long history of collaboration between CERN and FNAL operations.

The main areas of LARP activities are accelerator physics (experiments and simulation), long-term magnet design and production for the LHC IR upgrade, instrumentation and diagnostics, participation to LHC hardware and beam commissioning. It is clear that the last two activities are critical during the upcoming LHC commissioning. FNAL has a clear leadership role in the LARP organization.

The overall LARP strategy of delivering systems and services to the LHC that are relevant but not critical on "day one" of commissioning or early operations is reasonable, given that it is not realistic for CERN or any host laboratory, to delegate responsibility for mission critical systems.

There has been clear progress in the last year in the planning of FNAL accelerator personnel presence at CERN, for the current and next year. FNAL personnel are already stationed at CERN for interaction region and hardware commissioning tasks. Nine people are slated to be at CERN in 2007 and the first part of 2008 from LARP, and six are from FNAL. The plan for accelerator commissioning presence and contribution of LARP during the commissioning are more concrete now, and are focused on areas of FNAL expertise and responsibility.

FNAL has taken the initiative to collaborate directly in the development of beam operations software with the Controls and Operations groups at CERN (LAFS), an area that LARP does not cover in its plan and where FNAL has ample experience. This has the potential of providing useful tools for the LHC and to make optimal use of the infrastructure provided by LHC@FNAL. In fact, practical and really needed common projects are a necessary condition for remote collaborations to work.

5. 2 Fermilab CMS activities

With the first low-energy collisions in the LHC expected at the end of this year, this is a time of intense activity in installation, commissioning, and planning for data taking. Installation and completion of the CMS detector have the highest priority, and Fermilab is contributing strongly to this effort with personnel at CERN as well as at FNAL. The Fermilab group is the largest of the US-CMS groups, with about 50 CMS physicists at FNAL, including 3 Wilson Fellows and 7 postdocs. It is playing a major part in CMS work on detector construction and installation. Fermilab is also the US-CMS host laboratory and will have the only CMS Tier-1 center in the US.

Fermilab has constructed significant parts of several major subsystems, including the HCAL, Muon End Cap, Silicon Tracker, Forward Pixel Detector, and parts of the DAQ system.

The detector has successfully operated above ground during a cosmic ray run last year, and is now being assembled underground. The HCAL detector is being installed and tested now in the cavern. The Silicon Strip Tracker has been completed at the Tracker Integration Facility at CERN, and is being tested above ground with cosmic rays (and is functioning very well, with only 0.07% bad channels). The Forward Pixel Pilot Run Detector was completed at Fermilab, shipped to CERN, and is now being assembled there.

The current plan is to take data at 900 GeV in November 2007, but without the pixel or ECAL Endcaps. The full tracker should be ready for installation in July, but the schedule is extremely tight. Responding to a request from CMS management at CERN, Fermilab is making a special effort to provide additional help to meet the very tight schedule. At present, there are about 10 FNAL personnel working on installation at CERN. The Committee believes the CMS group has done an excellent job both in their detector work and in their current commissioning activities.

As the host of the only CMS Tier-1 center in the US, FNAL is taking a leading role in computing, commissioning, and plans for data analysis. It has established the LHC Physics Center (LPC), intended to provide support for a critical mass of active researchers and analysis experts, and to be the focal point of US analysis activity. During the last year, the LPC attracted ~200 visitors, and has provided several software tutorial programs, each attracting 20-40 students. Fermilab has also designed and built the Remote Operations Center (ROC), which should provide US physicists the same online access to detector and accelerator operations that they would have at CERN. The ROC seems to be a very well thought out operations center with multiple work areas for both analysis and controls, with excellent visualization and controls facilities. The Committee was given a brief tour of this facility, and was impressed with the layout, the design, and the resources provided to the operator. In fact, the layout and scope of the ROC are now being copied by the CMS collaboration for a similar control center being built at CERN. The Visiting Committee believes both of these projects were well chosen, and appear to be already having a very positive affect on the collaboration and on the Fermilab role in CMS analysis work.

The importance of LHC/CMS work is clearly recognized by Fermilab management, which has made "CMS Center" a new element in the FNAL organization reporting directly to the Associate Director for Research. It encompasses the LHC Physics Center LPC, the Remote Operations Center ROC, and the CMS Tier-1 Computing and Analysis Facilities LPC-CAF. For the future, US-CMS has submitted an EOI for CMS upgrade for $145M starting in 2010, and including pixel, tracker, and trigger upgrades.

Recommendations

- Consider negotiating access to operations information for US collaborators (i.e. access to e-logs and commissioning plans) from the start of LHC operations, even if it is CERN policy not to grant – understandably– full active access to the LHC control system. Establish priority with CERN to ensure remote connectivity and operations with FNAL.

- Focus on providing practical contributions to the LHC operations software and applications (LAFS) to make remote collaboration a reality.

- We fully endorse the Laboratory's strong support of CMS construction and commissioning through presence of FNAL personnel at CERN and active use by the entire US CMS community of the ROC.

- We also believe Fermilab has done very well in supporting CMS and building a strong center and infrastructure for CMS activity at Fermilab. The next year should also include a sharper focus on specific physics objectives of early LHC running.

6 ILC Accelerator and Detector R&D

6.1 Accelerator R&D

ILC Test Accelerator

The Committee was both pleased and impressed with the ongoing installation of new infrastructure for ILC cryomodule assembly and testing. The progress to date and future plans are consistent with the high priority the Laboratory has accorded the ILC project. FNAL has remained true to its commitment to build a core competency in the SCRF Main Linac technology. The refurbishment of the New Muon Laboratory (NML) and the installation of clean-room cryomodule assembly areas – as well as cavity and cryomodule test infrastructure – are now almost complete. FNAL is awaiting the delivery of a cryomodule kit from DESY this fall, which will be used to gain first assembly experience in the new facilities. The Committee acknowledges that this will be a major milestone for the Laboratory's plans.

The primary focus of R&D effort for the next three years is on construction of the ILC Test Accelerator (ILCTA), consisting of a single ILC-like RF unit with beam, to be located in the refurbished NML hall. The current plans call for the construction, assembly and test of one cryomodule per year (including the DESY kit this year); this will have a three-module RF unit available in 2009. Installation of the third cryomodule will require extension to the existing building and a new cryo-plant, the construction of which is scheduled to begin in 2008. These three cryomodules will then be replaced over the following two years with ILC-like modules (prototypes), leading to a full ILC-like RF unit test with beam in 2011. The current plans for the ILCTA are in line with the findings of the Global Design Effort (GDE) "S2" task force findings on the need for a linac string test. The Committee shares the concerns of the Laboratory that achieving even the single RF unit test by 2011 remains critical given the current funding profiles.

High-gradient SCRF cavity fabrication and surface preparation continue to be collaborative efforts in the US, with the necessary infrastructure and expertise being distributed amongst several key institutes. FNAL plays an important role as the central coordinating and assembly facility. The Committee notes and strongly endorses the need for the Laboratory to establish a core competency in the SCRF technology, which is currently limited by funding

availability. However, the Committee also notes that it will take several years for FNAL to become a world leader in this technology

Accelerator Physics

The plans to extend ILCTA beyond the S2 task force requirements to a general facility for Advanced Accelerator R&D (AARD) seem reasonable and fit well with the overall philosophy of the Laboratory. The facility is envisioned to provide an ILC-like test beam for the global community. While the Committee acknowledges that such a facility would primarily be driven by ILC requirements, it urges some caution in making sure that construction of the facility does not re-direct already limited resources from more critical ILC R&D.

The Committee endorses the continued ramp-up of linear collider accelerator physics expertise, again mainly focused on the Main Linac. The Committee is pleased to see this group becoming part of the newly formed Accelerator Physics Center, where it can benefit from synergy with other accelerator R&D projects at FNAL.

6.2 Detector R&D

The Laboratory has made good progress on a program of ILC detector R&D activities that are integrated with the broader U.S. program. Much of the work is done in collaboration with universities and other labs in the U.S. and abroad, and Fermilab has hosted numerous conferences and workshops on detector development and on developing detector requirements from the viewpoint of the physics requirements of the experiment.

The ILC detectors (tracking and others) will use unprecedented numbers of silicon detectors with characteristics beyond the current state of the art. Current device R&D focuses on integrating detectors and front-end electronics to reduce material. Other related work focuses on developing very-low mass support structures. The tracking hardware R&D is being closely coupled to software development in the computing division. The work is done in collaboration with other labs and with industry.

Another focus of detector development is on Geiger-mode avalanche photo-diodes that could be used in a variety of ILC detectors as well as earlier applications (T2K and possibly CMS).

Fermilab has established the only hadron test beam facility in the US. This will be crucial in supporting ILC detector development. It will provide identified particle species over a wide range of energies with well-characterized kinematics.

6.3 Planning for the ILC

The Laboratory continues to work with the GDE to further the design of the ILC as a truly international project. FNAL made a significant contribution to the GDE Reference Design Report (RDR) during 2006. FNAL has played several key roles in both establishing the baseline

design of the machine, and producing associated value (cost) estimate. Of particular note was the contribution to the Conventional Facilities and Siting (civil construction), where FNAL showed particular leadership within an international group. As the US designated site, the Director has also shown foresight in building an ILC culture within the Laboratory itself, and via outreach to the greater community. The Committee acknowledges key initiatives (ILC Task Force, ILC Physics Team, ILC Center and Outreach) that help to further the project.

With the publication of the draft RDR, the ILC GDE is now planning an engineering design phase, leading up to the publication of an Engineering Design Report (EDR) in 2010. The Laboratory has a large engineering-based resource which is well-placed to make a major and significant contribution to the EDR phase. The on-going ILC R&D plans summarized in 6.1 will also be used to further engage US industry in the critical cryomodule production, with a view to eventual mass production. FNAL has a leadership role within the US in establishing contacts with the US industrial forum, and in developing collaboration with key industries in procuring the components for the ILCTA (industrialization).

Recommendations

- The Committee endorses the development of a potential ILC site on or near the FNAL site, as part of the US 'bid to host'. The Committee recommends that FNAL continue to show a strong leadership role in the ILC R&D program, working within the GDE while building on the strong national and international collaborations already in place and extending collaboration to other GDE institutes.

- Fermilab must actively pursue additional resources if it is to achieve its goal of becoming a world leader in SCRF technology in the near future..

- The Laboratory should continue to support strongly a broad program of in-house detector R&D, and also support for R&D by other US groups through direct collaboration and by providing resources such as engineering and test beams. This work should be integrated with international efforts.

7 Neutrino Physics

7.1 Current Neutrino Experiments: MINOS and MiniBooNe

The current complement of operating neutrino experiments at FNAL has had a very good year. After an extended shutdown, the current MINOS data collection rate is slightly higher than that of a year ago and is slowly increasing. The total data sample is now nearly twice that reported in their first published result on ν_μ oscillations. With the projected intensity improvements and planned running, MINOS should reach its design goal of a precise (~10%) measurement of the m_{23} mass splitting. First results from a search for ν_e appearance in the next year are also expected.

Recently, the MiniBooNe collaboration presented and submitted for publication its first result on the search for neutrino oscillations in the region of the reported LSND result. They rule out the interpretation of the LSND signal as a simple 2 neutrino oscillation effect (equal for neutrinos and anti-neutrinos) at ~98% confidence level. MiniBooNe has been running with anti-neutrinos for the past year and is in the process of developing a request to continue to run beyond 2007. Regardless of that decision, they still have a considerable suite of non-oscillation measurements to finalize.

7.2 Future Neutrino Experiments: Minerva, SciBooNE, and NOνA

The Laboratory has a range of planned experiments in neutrino physics starting in the next few years. SciBooNE is making progress on installation and will measure a variety of exclusive neutrino cross sections as a valuable resource in predicting backgrounds for oscillation experiments, particularly for the Japanese experiment T2K. The MINERνA collaboration is making good progress on preparing their experiment, which will make a similar suite of measurements with unprecedented precision at higher energies.

The NOνA experiment and NuMI beam-line improvements have been combined in a single project with a planned budget of $260M. It has received strong support from P5 and is in the final stages of preparation for a CD-2/3 review this summer. The collaboration expects a project start this fiscal year. However, the current funding profile will delay the start of data taking by up to one year. In addition, the planned budget is insufficient to build the detector as originally envisaged and a variety of redesigns and de-scoping plans are being pursued.

A set of possible scenarios for running NOνA with and without significant accelerator upgrades was described. NOνA has the goals of a search for $\nu_\mu \rightarrow \nu_e$ oscillations for $\sin^2(\theta_{13}) > 0.01$, a precise measurement of θ_{23}, and the beginnings of a study of the mass hierarchy and CP violation. In combination with T2K, the reach is improved. Even in relatively optimistic scenarios, this would require very long running times at high intensity, with both neutrino and anti-neutrino beams.

7.3 Longer Range Plan

The plan for a neutrino program at Fermilab beyond NOνA is currently unclear. Which program will be most productive depends on the value of θ_{13} and the available proton intensity, and θ_{13} will not be known for a number of years unless its value is close to the current limit. A set of possible scenarios based on the NuMI beam and one or more off-axis surface detectors (plus NOνA) was presented.

7.4 The Proton Plan

A phased approach to upgrading the proton intensity was presented, similar in approach to what has been previously presented. In this approach, beam power to the NUMI target would

improve first to ~400 kW during the Tevatron running era, and subsequently to 700 kW. This *campaign* (Proton Plan 2) has been subsumed into the NOνA project with a TPC for the NOνA experiment and the accelerator and NuMI upgrades (ANU) of $260M. Additional upgrades that would use the Accumulator ring (after the collider program ends) to increase the beam power to 1.2 MW were described. A similar upgrade (to 1 MW) described last year had an estimated cost of $32M; no estimate was presented for the cost for the upgrade to 1.2 MW. Possible performance limitations in this plan are still under study.

Recommendations

- The Laboratory should strongly support the ongoing and planned neutrino program. It should carefully monitor the projected NOνA performance in the light of the need to de-scope to stay within the budget cap.

- The Laboratory should support studies and appropriate R&D for the next generation of neutrino experiments. These studies should include both experiments using the current NUMI beamline as well as the option of a new beam pointed at a large underground detector, e.g. in DUSEL. The current program of R&D for large Liquid Argon detectors should be continued

- The Laboratory should aggressively pursue intensity upgrades as a cost-effective way of improving the reach of the neutrino program. The technical limitations of the upgrade to 1.2 MW should be understood. The cost of this upgrade should be determined.

8 Particle Astrophysics

Particle Astrophysics and Cosmology is the third leg of the FRA Science Strategy. The Fermilab astroparticle physics and cosmology program has a strong record of accomplishment, both in setting the agenda for the field and in training graduate students and postdocs. Today, Fermilab has an impressive portfolio of experimental and theoretical activities in support of this strategic element. The Center for Particle Astrophysics has brought all of these activities together in one place under the able leadership of interim Director Scott Dodelson, and a search is underway for a permanent Director, who will have a joint Fermilab/UChicago appointment.

The Committee congratulates the Center for Particle Astrophysics on its very successful second year of operations and on the hiring of an outstanding young astro-theorist. This new Associate Scientist creates a strong link to the Theory Group (and other particle physics activities). Fermilab continues to play a leading role in the quest to resolve fundamental questions about dark matter, dark energy, large-scale structure of the Universe and the highest energy particles in the Universe. Strong involvement in well-selected and important experiments has positioned Fermilab as one of the leading, if not the leading, centers for particle astrophysics in the world.

Phase II of the Sloan Digital Sky Survey (SDSS) will be complete in July 2008. For the second year in a row, SDSS is the astronomical observatory with the highest impact (as measured by the fraction of highest cited papers in astronomy that derived their data from that

observatory), outpacing HST, Keck, WMAP and ESO. With about 20 people involved in SDSS, the Laboratory is leading many areas of the SDSS project and SDSS science. For example, Fermilab scientists are leading the SDSS-II supernova survey which will provide important new data at intermediate redshifts ($z \sim 0.1$ to 0.3).

The Cryogenic Dark Matter Search (CDMS), located in the Soudan mine, has reached a sensitivity of 2×10^{-44} cm^2 for dark matter and is currently one of the most sensitive dark matter searches in the world. The 25 kg upgrade (CDMS25), if funded, will greatly improve the sensitivity and provide an important next step in the direct dark matter search. COUPP (Chicagoland Observatory for Underground Particle Physics) is a new experimental approach that uses a bubble chamber for direct detection of WIMPs hitting nuclei. One of the advantages of this method is its insensitivity to minimum ionizing particles. A particular strength of the technique is the search for WIMP particles with spin-dependent couplings.

Fermilab plays the leading role in the Dark Energy Survey (DES) which will use four independent methods to study the nature of the dark energy. This phase III dark energy project is in the P5 roadmap as well as the President's 2008 budget and should begin construction in 2008. In the longer term, the Lab is positioned to make significant contributions to SNAP, the SuperNova/Acceleration Probe, DOE's candidate for the Joint Dark Energy Mission (JDEM). The timing of JDEM should become better known this fall when the National Academies' Beyond Einstein Program Assessment Committee (BEPAC) recommends which of the Beyond Einstein missions should proceed first.

The Pierre Auger Observatory is now in an advanced construction state and has already collected data equivalent to three times the exposure of AGASA. Auger is a strong international collaboration, built from the ground up, and with no country holding a stake larger than 25%. Fermilab can be proud of the role it has played in making this project possible, from hosting the design effort to providing the project management. Auger will undoubtedly lead to a new precision in the exploration of highest energy cosmic rays and is expected to provide answers to several important questions about the origin and acceleration of the highest energy cosmic rays.

The recently initiated Computational Cosmology Initiative builds upon strengths at FNAL (Computing Division and the Center), connections with Chicago and positions Fermilab to play an even more active role in cosmological phenomenology. Before this initiative grows significantly, consideration must be given to the role that it will play in the larger cosmological computing scene, and how it might serve a larger user community.

Particle astrophysics is a very important part of the Lab's scientific activities and now also involves significant resources (38 scientists, 51 engineers and \$12.5M/yr), growing at an estimated 10%/year. Both are consistent with the FRA science strategy and recent strategic planning documents for the field (e.g., EPP2010).

While the program is very strong, we note that astroparticle physics at Fermilab is at a crossroads: SDSS is winding down; CDMS is entering a new phase; Auger is almost complete and serious planning for Auger North has begun; it will soon be known if JDEM will begin in FY08/09 or if it will be significantly delayed; and the co-founder of astrophysics at Fermilab has

left. The field of astroparticle physics is rapidly developing and changing. Critical decisions lie ahead related to future projects such as Auger North, CDMS25; and SNAP/JDEM. If the program at Fermilab is to maintain its status as one of the premier programs in the world, a Director for the Center must be hired soon so that decisions can be made soon about future directions. In making these decisions, it should be recognized that Fermilab is a national user facility.

Recommendations

- We recommend that the Director position for the Center for Particle Astrophysics be filled with an individual with stature and vision as soon as possible.

- We recommend that the Center for Particle Astrophysics continue with planning for and move forward with timely decisions for strategic directions in particle astrophysics and cosmology.

- The membership of the Physics Advisory Committee (PAC) must continue to include expertise in astrophysics and cosmology in order to provide sound advice on the increasing number of small to mid-size experiments being proposed in this dynamic field.

9 Particle Theory

The richness of the theoretical physics program at Fermilab is matched by few US institutions. The senior group members are well-respected experts in their fields, and the group as a whole leads the nation in terms of its service to the community. In addition, the group has a long tradition of being effective at mentoring and developing the careers of junior members.

The areas in which the theory program has had a particularly visible impact include:

- Lattice QCD: the group is an international leader in large-scale computations, which have produced impressive results in heavy-quark flavor physics and weak decays;
- Perturbative QCD and collider physics: Fermilab has traditionally hosted a strong group of world experts on NLO and NNLO perturbative calculations for collider physics (Tevatron, LHC, and ILC);
- Physics beyond the Standard Model: the theory group includes several members working on electroweak model building and the phenomenology of various extension of the Standard Model, including supersymmetry and extra dimensions;
- Neutrino and heavy-quark flavor physics: several theory-group members are experts on neutrino and heavy-quark physics as well as applications of effective field theory, maintaining close connections with experimental groups in this area;
- Cosmology: members of the theory group have contributed significantly to studies of baryogenesis and dark matter, particularly in supersymmetric models.

Overall, the group continues to maintain a high level of productivity of significant research accomplishments. It provides a variety of valuable services to the larger FNAL community, and its work is well matched with the mission and program of the Laboratory. The

last years have seen a vibrant program of lecture series, workshops and conferences organized by the Fermilab theory group, many of them on-site.

Senior group members are serving the larger HEP community in important ways by serving on a large number of panels and committees, often playing leading roles. Examples include HEPAP, P5, and other HEPAP subpanels, executive roles in the APS and DPF, and the board of the Aspen Center for Physics. They also serve on a number of internal committees at the Laboratory.

The Committee is pleased to note that the theory group continues to attract outstanding postdoctoral fellows and associate scientists. These young scientists play a crucial role in assimilating new developments, they interact well and frequently collaborate with senior staff members, and they are important engines driving research. Postdocs in the theory group continue to get very good positions after leaving the Laboratory. Many of them have become leaders in their fields.

In last year's report the Committee raised concern about the small number of Associate Scientists in the theory group (one at that time) and, as a result, a potential weakness in LHC-related physics areas, including perturbative QCD and collider phenomenology. We encouraged the theory group to remain open to a variety of possibilities, such as extending the reach of the group in physics beyond the Standard Model or strengthening the QCD or neutrino efforts. We are pleased to see that with recent hires, the group has rapidly moved in these very directions, and thus has strengthened its expertise in LHC-related phenomenology for many years to come.

As we approach the LHC era, and as the community prepares for an ILC proposal, Fermilab is emerging as the forefront particle physics laboratory in the US. It will be important for the theory group to maintain a central role in this transition period. We believe the group is well positioned to play this role. In light of this, the Committee is encouraged to see that a strong visitor program in the theory group has been maintained, which is a crucial element in any leadership role. Fermilab visitor fellowships continue to attract first-rate junior and senior scientists for extended stays at the Laboratory. In the years to come, we recommend that the theory group's visitor program be tightly intertwined with the LHC analysis center.

Recommendations

- As part of Fermilab's transition in the coming years, the theory group should continue to strengthen its role as a US center for particle phenomenology in the LHC era.

- Continue the excellent visitor program, coupling it with the activities of the LHC Physics Center, and continue the tradition of hosting community workshops and conferences.

10 Computing

Computing at Fermilab is undergoing a major expansion in both size and scope. This is not a new development, and has been underway for many years, but shows no signs of

diminishing. On the contrary, it is clear that computing will play an increasingly important part in Fermilab research over the next five years and beyond.

This expansion is being driven by three different types of development:

1. The very large data sets from LHC running require a significant increase in both scale and complexity of data analysis for the CMS experiment. Because of Fermilab's role as the only Tier-1 Computing Facility in the U.S., and its anticipated major role in CMS data analysis, this is a major challenge for the lab.
2. Globalization of data analysis and groups is increasing dramatically. This is also closely tied to new developments in grid computing, including the Open Science Grid (in which FNAL is playing a leading role) and Fermigrid. This also leads to new requirements in technology, and especially in security.
3. There are several new major initiatives that are growing rapidly, and will be important efforts for many years. These include the Lattice QCD program, the experimental and computational programs in astrophysics, and of course the CMS/LHC program.
4. Increases in computing size and scope appear are growing rapidly, with no evident plateau before 2012. Major challenges in equipment, size, planning, new technologies (and power and cooling) will have to be faced.

FNAL seems to be responding well to these pressures. Work in OSG and Fermigrid, and in the "Metropolitan Area Network" appears to be well considered. FNAL has clearly had a very major effect on CMS computing, and is providing strong support to that program. We expect Fermilab to be a major figure in CMS physics analysis in over the next decade.

Recommendations:

- The Computing Division's role as the provider of major computing resources to scientific collaborations centered at Fermilab continues to expand, and will be an increasingly important aspect of what it means to be a "Fermilab user" in the post-Tevatron era. The allocation of these computing resources should be carefully considered as part of Fermilab's strategic scientific planning.

- Computing workshops and tutorials are an important educational component in many areas, e.g. CMS, astrophysics and accelerators. Fermilab should continue to provide strong support for these user services.

11 Support of the User Community

The Committee had a useful discussion with Sacha Kopp, Chair of Fermilab's Users' Executive Committee (UEC). The Fermilab User's Organization is a vibrant and active group headed by the 13-member UEC, which is elected from a broad range of Fermilab experimental communities. The UEC continues to organize excellent annual users' meetings and facilitate communication between users. The Users' Organization, has also successfully organized other

large events, notably a meeting of the leaders of all DOE users' organizations. This led subsequently to visits to Congressional offices by 200 users, an impressive and timely achievement. Fermilab users respect and value Fermilab and the scientific opportunities provided by Fermilab.

However, the User's Organization appears to be at a crossroads. As Fermilab enters a period of transition in the coming years, the Users' Organization must also adapt. Of particular relevance for the Users' Organization is the transition from URA to FRA governance and the growing diversity of experimental activities at Fermilab. This transition is a source of concern for many Fermilab users. At the same time, it provides new opportunities to expand the definition of what it means to be a Fermilab user and to create a closer relationship with communities involved in non-accelerator based physics.

One particular issue that emerged is that the special relationship between Fermilab and the University of Chicago and other local universities is viewed with considerable "angst" by many Fermilab users. This is, in part, because of the lack of clear communication about the new relationships and the role of other universities that are more geographically distant. In this new era, where Fermilab is the only DOE lab devoted solely to HEP, when the energy frontier is about to move to CERN, and uncertainty about the future of elementary-particle physics in the U.S. abounds, a strong, positive relationship between the HEP Community and Fermilab is essential to survival of both.

Recommendations:

- Fermilab should strengthen its role as a truly national laboratory. As in any time of transition, there is uncertainty. Fermilab management is encouraged to continue efforts to open lines of communication and to be solicitous of opinions and suggestions from university users.

- Fermilab is encouraged to capitalize on new initiatives to strengthen ties with the university community. The FRA's HEP Community Initiative is an excellent opportunity to strengthen ties with university users, including not only universities in northern Illinois, but also those outside the local area. The Accelerator Center also presents another opportunity to support university users at both the faculty and graduate student levels.

- Fermilab should maintain adequate housing and office space for users. These resources are essential aspects of Fermilab's support for university users, especially those from small university groups. The Committee urges that these be maintained at levels conducive to productive work, and that Fermilab management ensure that there are adequate resources to be receptive to suggestions for improvements.

APPENDIX A: Charge to the 2007 FRA Visiting Committee

Although Fermilab is a single mission laboratory, its present scientific program is quite broad: encompassing experimental particles, accelerator physics and particle astrophysics. It includes collider and neutrino oscillation experiments, and the necessary accelerator operations and R&D for improving the existing accelerator complex. In addition, Fermilab plays a leading role in U.S. participation in the LHC, both on the accelerator side and in the CMS detector. Fermilab now stands as the primary laboratory for high-energy physics research in the U.S. and has been selected as the U.S. site for the International Linear Collider (ILC). Its future and the future of high energy physics (HEP) in the U.S. are now even more closely linked, carrying a primary role in the field as articulated by the HEPAP and P5 panels advising funding agencies. At the same time, it is vital for Fermilab to maintain an active and continuous program of producing physics results.

An advanced accelerator R&D program for future accelerators, focused primarily on the ILC, is an important component of the program. The Laboratory has an extensive program in experimental astrophysics, and has theory programs both in particle physics and astrophysics. The management of Fermilab has recently been contracted to the Fermilab Research Alliance (FRA). The FRA Visiting Committee for Fermilab is charged with reviewing the broad scientific program and commenting on its quality, soundness, overall balance, and future prospects. The Committee is also encouraged to comment on the Laboratory Director's plans and priorities for Fermilab.

In its response to this charge, the FRA Visiting Committee as part of its review should try to address the following questions:

i) How effectively is the Laboratory dealing with Collider Run II operational issues (for both accelerator and detector systems)? How realistic are the Laboratory's Run II goals in relation to current and expected collider performance, and in relation to anticipated LHC turn on and operations?

ii) How effectively is the Laboratory meeting the requirements of the current and recently operating neutrino experiments (MINOS and MiniBooNE)? Is the Laboratory adequately preparing for future neutrino experiments (e.g., NOνA and MINERνA)?

iii) Are the Laboratory's R&D and strategic planning activities appropriately matched to future opportunities and expectations? Is the Laboratory planning effectively for the transition of the energy frontier to the LHC? Are the resources and level of effort for ILC R&D appropriate in all areas, including ILC technical components, site specific issues, and detector R&D? Is the Laboratory's Proton Plan consistent with the emerging neutrino program? Is the Laboratory's

evolving strategic plan aligned well with the science strategy laid out in the successful FRA proposal to DOE?
(As a reference, see http://www.fra-hq.org/pdfs/Science_Strategy.pdf)

iv) Does the Laboratory's new Center for Particle Astrophysics have an appropriate strategic vision? Does the corresponding program have adequate resources to maintain a leadership role in this exciting and burgeoning field? Is the level of the Laboratory's staff and support appropriate for each of the current and proposed experimental collaborations?

v) Is the balance in the Laboratory between current programs and research and planning for future programs appropriate? Notwithstanding current budget difficulties, are adequate resources being applied to high priority activities? Is there adequate planning for the various alternatives related to ILC decision times and accelerator placement?

vi) Are there areas of scientific endeavor, where Fermilab has unique capability and could have a significant impact, which the Laboratory should pursue more vigorously? Are there programs in the Laboratory whose efforts require future review in order to determine whether they should continue?

vii) Have the new contract arrangements, as well as management and staff reorganizations, helped further the mission of the Laboratory? Does the Laboratory management provide the scientific leadership needed for Fermilab?

viii) Is Fermilab responding appropriately to the changes in the high energy physics landscape in the U.S.? Does it fulfill its role as the only laboratory solely devoted to high energy physics, the movement to the LHC, planning for the ILC and potential U.S. siting, as well as the growing possibilities for nonaccelerator science?

ix) Are there any particular issues requiring special attention by the FRA?

APPENDIX B: The Meeting Agenda

Friday, April 20

8:00	Executive Session	(30)	
8:30	Fermilab Science Strategy Include FRA Initiatives	(45)	Young Kee Kim
Energy Frontier			
9:15	Accelerator Operations/Performance	(30)	Ron Moore
9:45	Tevatron Research Program D0 and CDF coordinated speakers	(45)	Florencia Cannelli Marco Verzocchi
10:30	Break	(20)	
11:00	CMS Center and CMS Research	(30)	Lothar Bauerdick
11:30	LHC Machine Commissioning/Ops	(30)	Mike Syphers
12:00	Lunch	(60)	
13:00	Accelerator R&D (incl. ILC) Program	(35)	Sergei Nagaitsev
13:30	ILC Detector R&D and Test Beam	(25)	Marcel Demarteau
Neutrinos			
14:00	Neutrino Physics Program Overview	(30)	Niki Saoulidou
14:30	The NOvA Project	(30)	Ron Ray
15:00	Break	(20)	
Astroparticle Physics			
15:20	Center for Particle Astrophysics	(40)	Scott Dodelson
16:00	Executive Session	(120)	
18:00	End of Session		
18:30	Reception at Users Center		
19:00	Dinner at Chez Leon		

Saturday, April 21

8:30	Advanced Computing	(30)	Oliver Gutsche
9:00	Theoretical Physics: Directions	(30)	Bogdan Dobrescu
Longer Term Development			
9:30	Acc. Phys. Center and Simulation Prog.	(30)	Vladimir Shiltsev
10:00	User Organization and Concerns	(30)	Sacha Kopp
10:30	Break	(20)	
10:50	Executive Session	(100)	
12:30	Working Lunch (Exec. Session)	(30)	
13:00	Executive Session	(60)	
14:00	Close-out with Laboratory Management		
15:00	Adjourn		

APPENDIX C: Members of the 2007 FRA Visiting Committee for Fermilab Scientific Programs

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