July 6, 2010

Physics Advisory Committee Meeting

June 22-26, 2010

Draft Comments and Recommendations

(Charge elements given in italics)

Overview

The Fermilab Physics Advisory Committee (PAC) met to discuss the state of the Laboratory and its current and planned projects at the three frontiers of particle physics. The PAC warmly thanks the proponents of the various projects for excellent presentations and documentation made available to the Committee. The PAC was very impressed by the physics results from the many Fermilab experiments.

At the Energy Frontier, exciting physics from the LHC is starting to flow, with first physics results from CMS, including those analyses led by Fermilab scientists. In addition, the most recent projections of the integrated luminosity and energy profiles of the LHC open the opportunity of extending the running of the Tevatron and the smoothly operating CDF and DZero experiments by three years to increase their sensitivity to the Higgs boson, particularly in the low-mass region favored by electroweak Standard Model fits. Updates were also given on the progress and strategy in developing a compelling physics program for a muon collider.

At the Intensity Frontier, the status and plans for the Fermilab neutrino program, as well as Project X and its physics, were reviewed. Interesting possible differences between the properties of neutrinos and antineutrinos from MINOS and MiniBooNE were presented and further antineutrino-mode running in the NuMI and Booster beamlines considered.

The Fermilab Center for Particle Astrophysics addresses important questions at the Cosmic Frontier, and the Center's future plans were presented.

LHC/CMS

Please comment on the role of Fermilab scientists in the physics output of CMS and the Laboratory support of the US CMS community.

The LHC is delivering its first collisions and the detectors are performing excellently. The LHC physics program is broad and exciting and will offer the first glimpse of the Terascale. Fermilab has devoted a large effort to CMS, with both the participation of its own staff scientists and by providing support to the US CMS collaborators as the host US laboratory. These contributions to CMS have been outstanding and include a strong presence of Laboratory scientists in all aspects of detector, computing, and offline operations, as well as numerous leadership roles in both physics analysis and collaboration management. The LHC Physics Center provides an excellent environment that enables US collaborators to actively participate in CMS without the burden of traveling overseas, including taking remote shifts and leading data analyses. The Center should continue to develop programs to increase the impact of US physicists at the LHC. The recently initiated Fellowship Program is a good step in this direction.

Plans to upgrade the detector in conjunction with the accelerator luminosity upgrades are underway and the scope of the work to be carried out by Fermilab is appropriate. The Committee is concerned about the redirection of funds by US funding agencies for the LHC-specific detector upgrade R&D and the impact that this will have on the US participation in the future of the LHC. The PAC recommends that the Laboratory work with the experiments and the funding agencies to ensure there is an appropriate level of support.

Tevatron Run Extension

Please comment on the physics value of an additional three years of running the Tevatron Collider program.

The proposed three-year extension of the Tevatron run, giving an additional 7 fb^{-1} of luminosity delivered to each experiment, provides a unique opportunity for Fermilab due to recent changes in the LHC schedule that could not have been foreseen.. The Tevatron Collider as well as the CDF and DZero detectors are currently operating at the peak of their performance, which gives confidence that this proposal can be successfully carried out.

Verification of the Higgs mechanism of electroweak symmetry breaking is one of the top goals of present-day high-energy physics and is the primary motivation for this run extension. Based on current understanding, a three-year extension offers a greater than 50% probability of obtaining evidence for a Standard Model Higgs at the three-sigma level over the full mass region favored by electroweak precision measurements, M_{Higgs} = 115 – 186 GeV. In particular, the opportunity in the low-mass region has been opened by the current projected luminosity and energy profile of the LHC. The extension of the current run would maintain the leading position of the Tevatron for this search over the next several years. The Tevatron has sensitivity to the dominant *b b*-bar decay channel which is complementary to the search modes at the LHC in this

mass region. In the case that no evidence is observed, the full favored region could be excluded at high confidence level, which would be in contradiction with the Standard Model.

In addition to this primary motivation, there are a number of exciting measurements that would be enabled by the extended run. The Supersymmetric Higgs five-sigma discovery potential covers an interesting region of the SUSY parameter space and would be competitive over this time period. The *p p*-bar environment of the Tevatron is ideal for study of the forward-backward asymmetry of the top-quark; and there is also a clear advantage for the measurement of the di-muon charge asymmetry. Both of these results currently deviate from the Standard Model prediction at the two-to-three-sigma level and would benefit from an extension of the Tevatron operations. Further improvement could be obtained on the measurement of the top-quark and *W* boson masses, tightening the electroweak precision constraints. In all, the Tevatron boasts a very broad physics program which has the capability to foster numerous Ph.D. students.

The PAC considers this to be an exciting and compelling physics opportunity with potentially historic importance. However, before making a recommendation, the Committee would like to receive information on the following (in no special order) to address its concerns:

- Impact of the extended run on the physics capabilities of NOνA
- Impact of the extended run on the long-term program of the Laboratory
- Detailed impact on the Higgs analysis due to any detector degradation from the extended run
- Resolution on the Higgs mass that is achievable in case evidence for the SM Higgs is found. The current combined search shows an excess of one-sigma significance over the broad mass range 100 to 155 GeV. Is this consistent with the behavior expected for a true signal?
- More detailed and up-to-date full-time equivalent personnel commitments of the collaborations for an extended run
- Projected increase in sensitivity which depends strongly on the successful achievement of anticipated improvements in the Higgs analyses. The PAC encourages the collaborations to report on the improvements that have already been accomplished compared to the presentations made to the PAC, and to provide updated projections.

Given this information, the PAC would be able to make a recommendation by early fall.

Neutrino Physics Program

Please comment on

1. *Status and plans for the Fermilab neutrino program.*

2. *The significance of the recent antineutrino results from MiniBooNE and MINOS and relevance for possible further antineutrino-mode running in the Booster Neutrino Beam and NuMI beam.*

Neutrino Beam Operations and Experiments

The PAC commends the Fermilab Accelerator Division for the superb operation of both the NuMI and Booster Neutrino Beam programs. The Committee was pleased to see the exciting new results from both the MINOS and MiniBooNE experiments on their antineutrino running and first events from the completed MINERνA detector. The PAC looks forward to the up-coming results from the SciBooNE and ArgoNeuT experiments. The Committee is also impressed with the progress that has been made on the construction of the NOνA experiment.

NuMI Beamline Running

Given the two-sigma difference currently observed between neutrinos and antineutrinos in the mass difference vs. mixing angle plane [Δm_{23}^2 and $\sin^2(2\ \theta_{23})$], the Committee recommends further antineutrino running for MINOS. For the NuMI beamline, there is a short-fall in the total number of protons on target (POT) required to satisfy the requested additional 2.5×10^{20} POT by MINOS with antineutrino running and the requested 4.9×10^{20} POT by MINERνA with neutrino running before the NOνA shutdown in March 2012. The Committee recommends sharing the short-fall of POT such that MINOS receives ~90% of the total requested POT for antineutrino running and MINERνA receives ~90% of the total requested POT for neutrino running - assuming the current operation capabilities of the NuMI beamline.

Booster Neutrino Beamline Running

For the Booster Neutrino Beamline, the MiniBooNE experiment has already received 6.5×10^{20} POT in antineutrino mode, and is expected to receive approximately 8×10^{20} POT by May 2011. This represents 80% of the 10×10^{20} POT in antineutrino mode requested by this experiment. Work to prepare the MiniBooNE Hall for installation of the MicroBooNE experiment may need to commence in May 2011. The Committee recommends that MicroBooNE be given priority in the detailed scheduling of the end of MiniBooNE running and the preparations for MicroBooNE installation. Given the new antineutrino results from MiniBooNE and the expected results from the combined analysis of SciBooNE and MiniBooNE, the Committee also recommends that the Laboratory revisit that part of the Letter of Intent, P-1002, to move the MiniBooNE detector to half the baseline of the current MiniBooNE experiment.

LBNE

Building on the unique infrastructure of Fermilab, related to the proposed Deep Underground Science and Engineering Laboratory (DUSEL), the community is developing a world-leading long-baseline neutrino experiment (LBNE) that addresses the measurement of the mixing parameter θ_{13}, the mass hierarchy, and CP violation in the neutrino sector as its principal goals. The experiment also provides new capabilities to search for proton decay and to observe neutrinos from astrophysical sources.

The PAC is pleased that the LBNE collaboration has now grown to 54 institutions, including six non-U.S. institutions. Fermilab responsibilities are project management, beam, and a liquid-argon far detector, while Los Alamos National Laboratory and Brookhaven National Laboratory have responsibility for the near detector and water-Cerenkov far detector, respectively. Several technology choices for the near detector are under consideration including: a design similar to MINERνA, a straw-tube tracker, and liquid argon. Far detector experimental configurations using two 100 kT water Cerenkov detectors, two 20 kT liquid-argon detectors, or one of each are being assessed by the recently appointed Physics Working Group (PWG). The goal is the greatest capability for neutrino oscillations and proton decay within the available funding. The PWG will determine and compare the sensitivity of each physics topic for each detector configuration by conducting simulations using common tools to determine detection efficiency and background rejection. The PWG physics report is due in late summer, and will be the primary input to the collaboration's detector configuration recommendation.

The Project Office will estimate the cost and schedule of each configuration using a common costing methodology and conduct a risk analysis (technical, cost, and schedule) for each detector technology and far-detector depth. LBNE plans to constitute a Collaboration Executive Committee as an advisory committee charged to make recommendations on the configuration choice, summarized in a single consensus report.

Discussions are underway to clearly define the boundary of responsibilities between DUSEL and LBNE, and a memorandum of understanding is expected to be in place this fall.

Continuing effective collaboration between the NSF and DOE on DUSEL and LBNE is crucial. There will be a Director's CD-1 Design Review and Cost, Schedule, and Management Review in the fall in preparation for a DOE CD-1 Review in December. (CD-1 does not require a detector technology choice.)

The PAC was pleased to hear that its recommendations to employ common simulation tools and common cost methodology for the comparison of water-Cerenkov and liquid-argon technologies have been adopted.

The PAC notes the progress that is being made by LBNE. However, based on the material presented, the schedule is aggressive. There is concern that the PWG has only been recently constituted and no updated simulations were presented. More resources should be channeled to this effort to meet the timeline of the DOE CD-1 review this December, which is driven by the DUSEL and LBNE schedules.

The PAC encourages Fermilab and LBNE to continue to work proactively to increase the international component of the collaboration.

Muon Collider

Please comment on the plans and progress in developing the physics program for a muon collider, the roles of Fermilab staff and the broader community, and how best to move forward in this area.

If the significant technical challenges of a multi-TeV muon collider are met, it may be a viable choice for an accelerator on the Fermilab site if results from the LHC indicate that a collision energy higher than 1 TeV is needed. A muon collider is well aligned with Project X and the longer-term program of Fermilab since the front end of a neutrino factory and a muon collider are the same, and the acceleration technology of the front end is similar to the ILC. The PAC is encouraged by simulation results indicating substantially lower backgrounds in a muon collider detector than shown by previous studies due to a new compact lattice design for the muon storage ring, as well as optimization of magnets and the machine-detector interface. However, the effects of high subdetector occupancy throughout the detector volume on object reconstruction and benchmark physics analyses still need to be thoroughly studied.

The PAC is encouraged by the recent submission of the Muon Accelerator Proposal (MAP) as an excellent first step to establish feasibility of the machine and to give an estimated cost range in FY 2016. However, the PAC has concerns that not enough resources are being dedicated by Fermilab to make a competitive alternative case to CLIC, given the level of resources committed by CERN to the development of CLIC. A plan with milestones to achieve the mature accelerator design beyond the work of the MAP Collaboration, and future presentation to the PAC on the progress of muon collider accelerator R&D would be helpful. It is emphasized that the Committee would expect Fermilab to be a major player in whichever of the lepton collider options is realized.

Fermilab is urged to continue efforts to involve the broader community including universities, international partners, and other national laboratories in physics activities such as simulations and participation in further workshops. The PAC expects that the broad university involvement achieved for the ILC will continue with the muon collider due to the many commonalities

between the ILC, CLIC, and the muon collider. The strategy for Fermilab to lead the muon collider physics and detector program resulting in a conceptual design report appears sound, and is needed to compare different lepton collider options, but again needs increased participation by the community.

The PAC is very pleased that the five national high-energy-physics laboratories have developed a white paper on physics and detector R&D at lepton colliders. The Committee encourages the continued coordination of physics studies for lepton colliders with the American Linear Collider Physics Working Groups. The PAC was impressed by the detector development R&D geared towards muon collider applications, and see this as an effective way to continue these worthwhile efforts. The Committee strongly supports Fermilab's proposal to DOE for additional funds.

Particle Astrophysics

"Please comment on choices made to focus the program. We would welcome any suggestions on how best to respond to the opportunities and potentially very limiting budget scenarios of the near-term future."

The Fermilab Center for Particle Astrophysics (FCPA) program is strong and generally aligns well with P5 and PASAG priorities. Unfortunately, the Committee was told that the FCPA now has a ~$1M structural shortfall, not including the possible DES operations shortfall of comparable size discussed below. The exciting scientific opportunities outlined in the P5 and PASAG reports could justify an increase in funding for the national non-accelerator program. The Laboratory is in an excellent position to help articulate the scientific case for this. In addition, when particle astrophysics experiments increase in scale, it is important that the component at the national laboratories increases to support those efforts when needed. This combination of scientific opportunities in the midst of budgetary shortfalls sets the context for the Committee's comments on the FCPA program.

A DOE review of the non-accelerator-physics programs at the national laboratories will take place in the fall, shortly after the release of the Astro2010 Decadal Survey report. The Committee commends the FCPA's use of its April retreat as a dry run. It is important for Fermilab to articulate a clear vision for the FCPA program at the review. As this is a national program, there is also great value in the national laboratories presenting a unified effort, and the FCPA Director should be proactive to ensure this coordination happens well in advance of the review.

The main components of the program are in dark energy and dark matter, along with smaller efforts in other areas of particle astrophysics. Specific comments about each area are below.

Dark Energy

The flagship project of the FCPA is the Dark Energy Survey (DES). The Committee was impressed with progress on DECam, the camera and infrastructure at the heart of the DES project. DECam is on schedule for delivery to the telescope in June 2011, with first light in January 2012. The Committee is concerned that the planning and budget for the commissioning and operations phases of the DES are not yet defined. The Committee advises the Laboratory to investigate this situation immediately. The DES is the top-priority and largest FCPA project, and so it has a large impact on the rest of the FCPA program. More generally, the Committee encourages the Laboratory to be more proactive in reviewing all high-priority FCPA projects over their entire lifecycle, including all aspects of the operation plans.

Early planning for a spectroscopic follow-on to DES, DECSpec, was briefly presented. The science potential and the ability to re-use much of the DES infrastructure make a compelling case for pursuing the possibility of DECSpec. A similar spectroscopic survey, BigBOSS, is already in development at Lawrence Berkeley National Laboratory and other institutes with the same science goals as DECSpec. The Committee strongly encourages the DECSpec group to discuss collaboration with the BigBOSS groups now so the development can be coherent.

The science that would be enabled by the Joint Dark Energy Mission (JDEM) is compelling, and the Committee reiterates its view that the JDEM Science Operations Center is an appropriate role for Fermilab. The future of JDEM is presently unclear, however, both in scope and in possible international partnerships. Hopefully with the release of the Astro2010 Decadal Survey report on astronomy and astrophysics later this year, the situation will be clearer.

Dark Matter

The FCPA is playing a central role in two dark-matter-search experiments: CDMS (low-temperature germanium detectors) and COUPP (room-temperature bubble chamber). The Laboratory has also granted Stage-I approval for participation in DarkSide, a promising approach based on liquid argon, which would be highly synergistic with the neutrino liquid-argon program at Fermilab. As with the two other projects, the DarkSide university groups would strongly benefit from the technical expertise and engineering support from the Laboratory.

Although this program has grown successfully by individual opportunities, a coherent FCPA strategy in direct detection of dark matter should now be clearly articulated. The unique and essential roles of Fermilab and the coordination and collaboration with other laboratories and universities should be included.

Within this overall vision, it should be a priority for the Fermilab dark matter effort to expand as necessary to support the national dark matter program, which is expected to grow in the coming years.

Other Efforts

The FCPA is involved in a number of other important programs. The Laboratory cannot continue all of these other efforts under the anticipated budgetary constraints. Difficult choices would have to be made, within a coherent strategy following the guidance of the PASAG, P5, and Decadal Survey reports, while preserving some capability for new initiatives. The Laboratory should give significantly lower priority to programs whose scope at Fermilab decreases below the point at which the FCPA can make an outstanding contribution commensurate with a national laboratory role. This may have painful national/international consequences. Thus, the Committee encourages Laboratory management to consider attempts to obtain budgetary increases within the context of an expanding national Cosmic Frontier program.

Per previous PAC reports, the Committee recommends that the Laboratory provide a written summary of the recent informal holometer theory review.

The computing needs at all levels (cosmological simulations, data analysis, facility development, etc.) should be clearly articulated by the FCPA and the Computing Division, and the plans should be updated regularly.

Project-X Experiment Planning and Physics Opportunities

Please comment on the plans and progress in developing the physics program for Project X, the roles of Fermilab staff and the broader community, and how best to move forward in this area.

Developments towards the definition of Project X specifications have proceeded well during the past year. Following a series of workshops and discussions with the communities of accelerator physicists, experimentalists, and theorists, the preferred accelerator option emerged by consensus as IC-2, a 3 GeV continuous-beam superconducting linear accelerator with 1 mA current followed by a downstream accelerator raising the energy to 8 GeV for injection into the Main Injector. This approach can simultaneously supply 2 MW to the neutrino program, 1 MW of suitably time-structured beam to both muon and kaon experimental areas, and 0.5 MW to a program of fundamental studies involving nuclei. A "White Paper" outlining the leading physics opportunities of Project X as currently conceived was prepared by a group consisting of scientists from Fermilab, US universities, other US national laboratories, and international institutions. The leading experimental opportunities accessible at Project X include long baseline neutrino oscillations seeking evidence or measurement of CP violation, lepton-flavor-violating muon reactions, particularly μ-e conversion and rare kaon decays $K^+ \to \pi^+ \nu\bar{\nu}$ and $K_L^0 \to \pi^0 \nu\bar{\nu}$ sensitive to non-standard-model physics, and fundamental experiments with nuclei. Other potential applications including R&D for accelerator driven sub-critical reactors and transmutation of nuclear waste have been suggested recently. The feasibility of these suggestions will be investigated in the future.

To further develop the physics programs and experimental planning for Project X, four working groups for neutrinos, muons, kaons, and nuclear physics were set up. In these working groups, requirements and specifications for beamlines and detectors for each physics program will be discussed with the Fermilab accelerator physicists and detector physicists. Additional meetings of the working groups are planned for the fall 2010 and a comprehensive workshop is planned for the spring 2011.

Now that the science possibilities have been explored, it is appropriate for Fermilab to outline the plan for complete development of the Project-X proposal, including the route to CD-0. Elements of the plan should include specification of the machine configuration and initial set of experiments with cost estimates, assessment of international interest, and an appropriate set of workshops and presentations involving the broader national and international physics communities.

Decommissioning Plans

Please comment on how you see the Fermilab program strategy affecting the various decommissioning plans presented; how the strategy affects the order and nature of the decommissioning efforts.

The PAC was presented with plans and cost estimates for decommissioning the Tevatron and the associated experiments. Keeping the Tevatron cold after the Collider runs are completed could be done at a cost of $4M/year, which would insure against possible component failures should the Tevatron need to be reinstated. This cost would only be justified if a compelling case were made for the Tevatron's future use. The situation needs to be revisited no later than six months prior to the Tevatron's shutdown.

CDF and DZero provided estimates of the cost and manpower needed for decommissioning. The cost estimates differ ($50M for DZero and $26M for CDF, both including 100% contingency), likely because of different assumptions made (e.g. CDF did not account for infrastructure decommissioning). The decommissioning plans are at a reasonable level of detail. The PAC recommends that Fermilab makes efforts to minimize the cost and time of decommissioning.

Other Topics

We welcome any comments you have on the Fermilab program or issues raised in any of the presentations.

Computing

Computing is fundamental to the scientific program of the Laboratory, and the Computing Division supports the entire Fermilab program. Funding for computing and software infrastructure for experiments is not normally included in project construction budgets, but rather is a component of detector operations, and there are many demands on detector operations. During the R&D phase of experiments, support for offline and computing is funded by the Laboratory-wide research program.

The PAC stresses the importance of experiments being aware of the need to identify necessary computing and software resource requirements for *all* phases of the experiments. Requirements for computing resources should be explicitly included in both R&D and operations planning, including personnel needs for simulations in R&D and construction phases. Since large computer purchases take many months, the operations plan for computing should be in place well before the experiment begins data-taking.

The LHC and Tevatron experiments have well-established processes for defining computing requirements. The experiments express their needs in terms of CPU, disk, tape, and manpower resources that are reviewed annually. Where computing resources for a Fermilab experiment are not large, a more streamlined process for defining computing requirements is recommended.