Fermilab Physics Advisory Committee Meeting
2013 June 4-8
Comments and Recommendations

Introduction

The Fermilab Physics Advisory Committee (PAC) met near the Aspen Room of the Lisle, IL, Hilton, at a time of important transitions: the Laboratory will soon have a new director; the DOE Office of Science will soon have a new director; the U.S. particle physics community is considering a wide range of future opportunities in an extended "Snowmass" process culminating this summer; and soon thereafter another Particle Physics Project Prioritization Panel (P5) process will launch.

The Laboratory experienced unusually large funding cuts in FY13-14. The PAC commends FNAL management for its skillful handling of the additional reductions in a manner that mitigated the immediate consequences, yet the impacts are still painful: the future flagship LBNE project is delayed one year; the Proton Improvement Plan (PIP), which is vital to the accelerator complex infrastructure and maintenance of efficient operations, is delayed one year; the near-term flux to the current flagship NOvA experiment is reduced up to 20%, stretching out the required running time; and R&D programs that determine the future of US accelerator and detector leadership are eliminated or significantly curtailed. Reduction in core skilled staff was a common theme in discussions of the status of the various Laboratory activities. The short-term cuts are painful, but manageable; however, the mid-term and long-term impacts of continued cuts would seriously damage US competitiveness in particle physics.

The PAC considered several issues regarding Laboratory scientific activities, one proposal (P-1028 NuSTORM), and two letters/expressions of intent (P-1039 Polarized Target Drell-Yan and P-1040 CENNS). The PAC also heard updates on the Proton Improvement Plan, LBNE, Project X, NOvA, MicroBooNE, CMS, Detector and Accelerator R&D programs, IARC, Mu2e, the activities of the Center for Particle Astrophysics (including separate talks on Direct Detection Dark Matter experiments and DES), and preparations for the Snowmass meeting. Although several of the topics touched upon muon collider R&D, a status report of the ongoing MICE project was not given, and a presentation at the next meeting would be appreciated by the PAC.

The Committee greatly appreciates the time and effort required of the proponents and presenters to prepare the materials for this meeting. As usual, Steve Geer was very

helpful in all PAC matters, and the dedicated support and excellent problem-solving skills of Hema Ramamoorthi are also very much appreciated.

The Committee thanks Young-Kee Kim, the Fermilab Deputy Director, for reporting the overall status of Laboratory programs and key issues facing the Management, and for her many years of hard work as a leader of the Laboratory.

Finally, the PAC gives special thanks to Director Pier Oddone. His youthful enthusiasm for all of particle physics, clear and strategic thinking, and nimble navigation through a decade of complex challenges for the Laboratory and our field have been inspirational. *In bocca al lupo*, Pier! The PAC looks forward to welcoming the new director at its next meeting.

NuSTORM (P-1028)

The PAC received the proposal to build a muon storage ring facility to produce a neutrino beam from 3.8 GeV muon decays and a baseline set of near and far detectors. The PAC reiterates the opinion that such a configuration would provide an ideal and unique setup to study eV-scale oscillation physics in appearance and disappearance modes, to measure electron and muon neutrino cross-sections with an unprecedented precision, and to provide a test bed for muon accelerator technologies.

The Collaboration is commended for its comprehensive proposal, which includes detailed conceptual designs for the target region, the storage ring, and the conventional facilities for near and far detectors.

The PAC notes the small size of the Collaboration compared to the scale of the NuSTORM project, and encourages the team to find ways to enlarge the community interested in using the facility. In this regard, the PAC suggests that now would be an excellent time to welcome wider participation, as the project is in its formative stages. The PAC is especially interested in understanding potential collaboration with CERN.

The combination of a clear resolution of the short-baseline neutrino anomalies, the precise measurements of the neutrino cross-sections, and the synergy with neutrino-factory technology makes this an attractive and intriguing project. Resources are, of course, limited. The PAC therefore recommends Stage-1 approval and consideration at the upcoming Snowmass meeting and by P5.

EOI - Coherent Elastic Neutrino Nucleus Scattering (P-1040)

The PAC was presented with an innovative Expression of Interest (P-1040) to use the far-off-axis booster Neutrino Beam to discover Coherent Elastic Neutrino-Nucleus Scattering (CENNS). The Standard Model prediction for this process was made in the early 1970's, but a direct measurement has not yet occurred.

Although it was noted in the EoI that the CENNS mechanism is important in the modeling of supernova explosions, that it could be useful to search for effects due to sterile neutrinos, and that CENNS processes arising from solar and atmospheric neutrinos are irreducible backgrounds to future-generation dark matter experiments, the proponents have not made a compelling case that P-1040 would have significant impact in these areas. There were also concerns about the experiment: no notional error budget was presented to support the 5% measurement goal, and a significant amount of work would

be needed to show the required neutron background rejection is plausible. Finally, a unique reach within credible "Beyond SM" scenarios has not been established. Therefore, the PAC does not recommend supporting the effort as proposed. However, determination of the feasibility of using the low-energy flux from the stopped beam at Fermilab could be useful for other physics.

NOvA

The PAC is happy to see the impressive and steady progress in the installation and commissioning of portions of the detector at the Ash River site. As of June 2013, 14 PVC blocks, out of a total of 28, have been assembled and installed. Eight blocks are filled with liquid scintillator, of which two are fully outfitted with electronics and are collecting cosmic-ray data. The completion of NOvA construction is foreseen for spring 2014. In parallel, the Collaboration has done an impressive job to prepare for data taking, prompt detector calibration, and data analysis. Reconstruction and analysis groups have been formed and are ready to take advantage of the neutrino beam as soon as available. The accelerator and NUMI upgrades (ANU), essential for a successful NOvA program, will be completed soon. Regrettably, necessary upgrades at the Booster suffer from delays and will not likely be completed before early 2015. The PAC has expressed concerns about the negative impact on the physics of potential delays of the Booster upgrades. The PAC recommends that every effort be made to provide NOvA with a proton flux as close as possible to that of the original plan so that physics can be extracted in a competitive way within the international landscape. The PAC looks forward to hearing progress on this high-priority experiment.

LBNE

LBNE, which will probe the neutrino mass hierarchy and CP violation, is intended to be the flagship experiment in the future program of the Laboratory and a core component of the US HEP program. It has achieved a significant milestone with CD-1 approval in December 2012 for the Phase-I configuration, *i.e.*, a 10 kt detector on the surface with no near detector. The PAC congratulates the LBNE Collaboration and the Laboratory on that approval and on the many positive developments achieved.

Recent technical progress, particularly on the 35t prototype detector, is encouraging. The PAC is concerned about the state of understanding of the design of the photon detection system. This could have implications for the overall design of the detector and therefore must be understood as soon as possible. Furthermore, the extrapolation to 10kt is

significant. The PAC requests that a risk analysis is included in a status presentation at the next PAC meeting.

As noted previously, the PAC is also concerned about potential impacts of surface operation. The PAC commends the Collaboration on the recent progress in this area, however more work is still needed. In particular, it is critical to demonstrate surface operation capability with a realistic simulation of the TPC readout geometry and digitization.

The PAC was presented additional information on systematic uncertainties, which showed their importance and relevance on the projected sensitivity of the experiment. The PAC notes that demonstrating the possibility to reach the quoted goals for systematic errors is mandatory to justify a larger far-detector mass and/or increased beam power for the experiment provided by Project X. The PAC looks forward to updates on systematic error assessment starting at its next meeting.

The PAC was informed that a renewed priority is to install the far detector underground, at 4850 ft depth, and to build a near detector. An underground location enables sensitive proton decay searches and the detection of atmospheric and supernova neutrinos, as well as mitigating risks due to surface backgrounds. Given the cap on the LBNE project, the additional costs must be borne by non-DOE or international contributions. International developments since the previous PAC meeting have improved the prospects of such contributions. These include the interest of Indian physicists in the near detector, and the adoption of a new European strategy for particle physics, which identifies next-generation long-baseline neutrino experiments as one of its high-priority areas and states that European scientists should explore involvement in projects in the rest of the world.

In its October 2012 report, the PAC wrote that it, `*...encourages the collaboration to concentrate, for the immediate future, on the task at hand: designing a viable detector able to perform the physics at the surface. The ultimate goal is a larger detector underground for both high-intensity neutrino measurements and the other physics topics (such as proton decay and supernova neutrinos). Furthermore, a near detector will be needed. The PAC encourages the parallel efforts of the LBNE collaboration, in coordination with the Laboratory, to secure additional domestic and international participation to enhance the physics reach of Phase 1 as much as possible, including an underground option.*'

The PAC reaffirms this recommendation, emphasizing the major impacts that the enhancements beyond the baseline will have on LBNE science. Time is precious, and a strong international collaboration with the additional resources for enhancements (*i.e.*, a larger far detector underground and a near detector) must be developed as soon as possible.

Finally, while the PAC commends the Collaboration for its bold long-term vision, it is also important for the Collaboration to emphasize the science reach consistent within available Phase-1 scope, along with the improvements enabled by potential enhancements. The timescale and costs of the later phases are such that the Phase-1 physics program must be clearly stated, and it should be highlighted at the upcoming Snowmass meeting. The PAC recommends that substantially more effort be made by the Collaboration to communicate effectively the physics importance of Phase-1 LBNE, and the opportunities it creates, to the broader particle physics community and beyond.

MicroBooNE

The PAC congratulates the MicroBooNE Collaboration on its progress in detector construction. MicroBooNE is an innovative liquid argon detector that will perform important physics measurements. It will also demonstrate a technology and address a number of non-trivial issues, such as HV operation and operation without prior evacuation. While the PAC looks forward to the successful commissioning and neutrino data-taking phases, it stresses that the commissioning of such an innovative detector may require time. The PAC further recommends that, while every effort should be made to provide MicroBooNE with the needed beam intensity, protons should be subtracted from the NOvA program only when MicroBooNE commissioning is complete and the detector is capable of taking full advantage of the neutrino beam.

Drell-Yan Experiment with a Polarized Proton Target (P-1039)

Members of the SeaQuest Collaboration presented a proposal (P-1039) for a new Drell-Yan experiment at Fermilab. P-1039 proposes to perform the first measurement of the Sivers function of sea anti-quarks by adding a new LANL-designed polarized proton target to the existing E906 detector. No major changes are required to the beam line.

The physics addressed by P-1039 is similar to that addressed by P-1027, a proposal presented to the PAC in 2012. Both propose to perform measurements aiming to resolve the proton spin puzzle, a topic that is important to the nuclear physics community and is of interest to the high-energy physics community as well. While P-1027 aims to measure the Sivers function for valence quarks, P-1039 proposes to perform the same measurement on sea anti-quarks. Since there are indications from other experiments that the Sivers function for valence quarks is small, the measurement proposed by P-1039 is more promising in terms of providing a possible solution to the proton spin puzzle.

By using a polarized target instead of a polarized beam, P-1039 would address this interesting physics topic while keeping to a minimum the impact on the Fermilab accelerator division and the rest of the Fermilab physics program. This is not the case for P-1027, which requires significant resources to develop a polarized beam and which more severely disrupts the beam to NOvA.

The PAC also appreciates the opportunity offered by this proposal to continue the partnership between Fermilab and the nuclear physics community.

Given the pressure on the accelerator division and the overriding responsibility of the Lab to support its core neutrino program, the PAC recommends that priority should be given to P-1039 over P-1027, and hence recommends Stage-1 approval for P-1039, contingent on the funding from DOE Office of Nuclear Physics (NP) for the project and continued minimal impact on the high-priority core program. Because of the significantly smaller impact of P-1039 on the Fermilab infrastructure, NP funding could be easier to obtain and the experiment could start earlier.

Mu2e

The PAC heard a presentation by the Mu2e collaboration reviewing the physics motivation and recent progress of the experiment.

The Mu2e experiment studies charged lepton flavor violation by searching for muon conversion to an electron in the presence of a nucleus. The goal is to reach a single-event sensitivity of 2×10^{-17}, which represents an improvement of four orders of magnitude over the present limit. The rate predicted by the Standard model is extremely small, so Mu2e is a clean search for physics beyond the Standard Model that is sensitive to mass scales of several thousand TeV.

The proposed Mu2e experiment is complementary to searches for the flavor changing radiative decay ($\mu\rightarrow e\gamma$) currently being studied by the MEG collaboration at PSI. If the radiative decay were discovered, Mu2e should also see the muon to electron conversion coming from the case where the photon is virtual and interacts with the nucleus. The COMET experiment at J-PARC is in direct competition with Mu2e, so it is important to keep the experiment on schedule.

There has been significant progress in the design of the experiment and the preparation towards CD-2 approval. Such progress is particularly notable from the perspective of the concerns raised in the past by the PAC. Tracker, calorimeter, and extinction monitoring technologies have been chosen. Sophisticated simulation tools have been implemented to study backgrounds, detector resolutions, and beamline design in detail. Prototypes of the

straw tubes, solenoid, and target station are being prepared. Issues with heat and radiation shields, as well as impacts of neutrons, are being addressed.

The PAC encourages the Collaboration to continue its excellent progress with simulations and prototypes to identify and resolve possible problems that may delay the experiment. The PAC commends the Collaboration on the progress, and encourages the Laboratory to continue its strong support for the experiment, particularly given the competition.

Detector R&D

The PAC is impressed with the breadth and depth of the Fermilab detector R&D program. This program builds on the expertise of the engineers, technicians, and scientists at the Laboratory, in collaboration with outside institutions to develop cutting-edge technologies and new detectors for future experiments.

The LAr R&D program, with its dedicated facilities, is essential to support the design of Fermilab experiments, and it is also an important national facility.

Fermilab also provides a test beam facility to support detector R&D performed by university groups worldwide. This facility, which is in very high demand, will be expanded to include a new beam line and a new silicon strip telescope.

The PAC recognizes that the detector R&D program at Fermilab is essential for the Laboratory and the high-energy physics community. The PAC also encourages Fermilab to continue the LAr R&D program at the current level, possibly expanding it if needed. The PAC also encourages the timely publication of all R&D results.

Project X Facility

The PAC was presented an overview of the Project X facility, goals, status, and strategy. While the focus is particle physics, Project X will produce high-intensity proton beams of interest beyond HEP, including applications to materials development for fusion and fission energy sciences, as well as possibly unique nuclear physics research. The PAC congratulates the Project X team on the publication of the Reference Design Report, and it appreciates the updates on the status of both the technical work and the proposed schedule, including the three-stage "campaign" aiming to high priority physics experiments at the crux of the Intensity Frontier program.

As discussed at previous PAC meetings, fiscal constraints require a staging of the Project into three periods that match the planned physics program. Project X R&D remains vibrant even with the current budget restrictions. Mitigating critical technical risks will require Laboratory resources.

The Project X Injector Experiment (PXIE) is the centerpiece of the Project X R&D plan. It will address many of the front-end Project X technical challenges using Project X specified components. The PAC notes that PXIE is now a staged project as well.

Preparations for Snowmass appear to be considerable and strategic.

Project X Physics Developments

The PAC received a status report on evolving physics developments planned for Project X. The PAC is impressed with recent physics ideas, developed since the last PAC meeting, which include:

- Exploring the ability to set limits on nonstandard neutrino interactions at LBNE.
- Developing the possibility of using a neutrino factory beam from Fermilab to Homestake mine to make a high-precision determination of the CP violation parameter. This would use a lower proton beam energy from Stage 2 of Project X. Distinguishing antineutrino interactions from neutrino interactions would be possible using a magnetized detector.
- Advancing the development of the direct EDM measurement concept. Measurements of EDMs are intriguing particle physics probes of possible new physics, and Fermilab scientists are encouraged to investigate paths to applying unique Fermilab capabilities to this problem. In addition, it has been realized that, by using a small ring, a direct measurement of the electron EDM can be made. This would be useful for demonstrating concepts needed for the proton EDM

measurement and might provide a limit competitive with those inferred from atomic measurements.

The PAC finds these to be exciting additions to the overall Project X potential physics portfolio.

Among the products that will inform Snowmass and P5, the three-volume Project X physics resource book is particularly important and will be available prior to the Snowmass summer meeting.

Proton Improvement Plan (PIP)

The PAC learned of the many changes in the proton accelerator complex ongoing during the shutdown and beyond. The Proton Improvement Plan (PIP) involves more than a dozen improvements to the proton source and Linac, many of which are complete. Maintenance tasks were also completed in the Booster, but the significant task of refurbishing the 20 RF cavities is delayed by 1-2 years. Proton source operation at low intensity has begun, on schedule.

A two-month commissioning schedule for the NOvA beam at 330 kW will be followed by a gradual increase to 700 kW within the next 1-2 years, subject to choices in proton program planning and continued progress in booster cavity refurbishing.

The PIP has been an impressive success, undertaken with limited staff and resources. There is a continuing concern about maintenance of the remaining old infrastructure. Staying ahead of system failures is a constant issue. The PAC congratulates the Accelerator Division on completing its long list of projects on time and looks forward to reports on the progress toward high power beams.

CMS Physics and Upgrade

The PAC heard of CMS physics planning for the LHC high-luminosity future as well as the Upgrade Project. The CMS detector ran flawlessly, and the Collaboration demonstrated impressive commitment to prompt analysis of the data. Fermilab should be proud of its role as the lead U.S. laboratory and the intellectual home of the U.S. CMS Collaboration. The success of the Tier 1 and Tier 3 computing allowed U.S. physicists to play critical roles in the data analysis. Home-base support of 750 physicists realizes the shared vision of a vibrant community.

LPC scientists and the U.S. CMS computing management have been extremely helpful in the Snowmass effort to generate background simulations for the U.S. study.

The 8 TeV running of 30 fb^{-1} of luminosity is only the beginning, as much physics awaits the 13-14 TeV 2015 exposure. Future luminosities of $>2x10^{34}$ cm^{-2} s^{-1} in Phase 1 after 2018 will open new physics opportunities but will also create conditions that require significant modifications to the CMS detector. The U.S. responsibilities to these upgrades include improvements to the hadron calorimeter, forward pixel detector, and calorimeter and muon triggers which together provide important tools for dealing with the otherwise overwhelming pileup conditions.

Fermilab is responsible for management of the U.S. CMS upgrade project, which is well organized and includes major Laboratory and university construction activities. The PAC was informed that the search for the Project Manager and Deputy Project Manager is about to converge. The new managers will inherit a project well on its way to successful August CD-1 review and the complementary NSF proposal.

Accelerator R&D and IARC

Stewardship of Accelerator R&D is the responsibility of the DOE Office of High Energy Physics, and Fermilab is the home to the largest single piece of that important national effort. The PAC received a summary covering a number of accomplishments of this multifaceted program.

Fermilab has long fostered a laudable commitment to accelerator science as an intellectual activity. Indeed, the Fermilab Accelerator Physics group regularly publishes at a high rate, and they are to be commended for their continuing productivity. The scholarly effort and the cooperative mixture of experimental and theoretical accelerator science have resulted in a productive Ph.D. program at Fermilab, which sponsored 10 successful theses in approximately the last three years.

The lab relies on a separate Accelerator Advisory Committee (AAC), and the PAC suggests that periodic contact between the two committees could be valuable. One of the AAC's recent actions was to approve a proposal to DOE to re-invest in the ILC SRF Linac to transform it into the Advanced Superconducting Test Accelerator (ASTA) user facility. ASTA could be very useful to the U.S. Community, and the PAC hopes to hear of ASTA's progress at a subsequent meeting.

The PAC recognizes that the Accelerator R&D effort has had to contend with significant dislocation as a result of national reprioritization. Further, attrition of scientific personnel

has been a significant loss. The PAC agrees that a coherent national Accelerator R&D program is a high priority.

This group has been an active participant in the Snowmass study, contributing to the understanding of an electron-positron "Higgs Factory" and its associated challenges.

The PAC also heard of progress with the Illinois Accelerator Research Center (IARC). This is a unique partnership among Fermilab, the State of Illinois, and the Department of Energy to create a test bed and research hub for industrial, educational, and research clients in need of facilities, expertise, and beams. The State of Illinois funded the construction of a new building and lab space adjacent to the CDF hall and assembly areas. The potential clientele for this facility seems to be diverse and eager to utilize IARC. Currently beam facilities are an unmet need in many industrial settings and IARC will provide infrastructure designed to foster innovation and product testing. The PAC is intrigued by the continued development of IARC and commends the Lab management and senior scientists for transforming this unique idea into a reality.

Snowmass Process

Snowmass participation is divided into seven working groups: Energy Frontier, Intensity Frontier, Cosmic Frontier, Frontier Capabilities group, Instrumentation Frontier, the Computing Frontier and Education Outreach. The PAC heard presentations on the progress that some of these working groups were making (including participation of Project X, Accelerator R&D, NuSTORM, and LBNE as described in this report). As detailed throughout, it is important for Fermilab to highlight its physics program and present its roadmap for the future to the Snowmass meeting.

We encourage participation as broad as possible by Fermilab staff to provide support for their programs, which span all of the Frontiers.

One area in need of more effort is the preparation of the scientific case, including background mitigation, for a muon collider. Eagerly awaited muon collider machine background studies are nearly complete to a level at which meaningful physics simulations can be started. However, to date, very limited participation is evident in the relevant Snowmass Energy Frontier working groups, and an opportunity could be lost. The PAC requests an update on muon collider physics studies at its autumn meeting.

Cosmic Frontier Activities

The PAC notes the breadth and vitality of the particle astrophysics program and its good connections to the other activities in the Laboratory.

DES

The PAC congratulates the Collaboration for the successful completion of the project. DES is already operating as a community facility, and the survey is on track to start in September 2013. The Collaboration is addressing pressing funding needs to support the Data Management System. The PAC looks forward to updates at future meetings.

Holometer

The PAC heard a summary of the progress with the novel Holometer experiment, and notes that the project has a timeline of 2-3 years, with results at the desired sensitivity possibly delivered in an even shorter time frame. A swift and definitive completion of this interesting experiment is important.

Dark Matter

To define its program for second generation (G2) dark matter detectors, DOE initiated a down-selection process that narrowed the field to five competing groups, and it will further narrow the field with a selection in 2014. The PAC agrees that FNAL is generally well positioned as the host laboratory for three of the five groups (COUPP-500, DarkSide-G2, and Super-CDMS). The PAC strongly supports the stated intention to boost significantly the level of FTE staff scientists engaged in the G2 dark matter program, in part by transitioning effort as Auger ramps down, when the national dark matter experiment path is selected.

Future Activities

In its report from the October 2012 meeting, the PAC noted that, '*in the area of dark energy, the Lab is engaged fully in DES, is ramping up on LSST, and is carrying forward work on two competing spectroscopic survey concepts. The PAC is concerned that the Laboratory may be stretched too thinly in this area and suggests careful thought be given to prioritization and timely decision making. The PAC requests a brief update on the Lab's plans for LSST, DESpec, and BigBOSS at its summer meeting.*' An assessment of Fermilab involvement in future dark energy experiments was presented at this meeting. Over the next 1-2 years, experience will be gained with DES, the G2 dark matter selection will be complete, the Holometer will have results, and the Laboratory

roles in LSST will be more fully developed. The PAC therefore suggests that approximately 18 months from now might be a good time for another strategy retreat to consider new large-scale FCPA projects.