Fermilab Physics Advisory Committee Meeting
July 23-25, 2014
Comments and Recommendations

Introduction

The Physics Advisory Committee (PAC) met at the Chicago Gleacher Center at a very important time for the US particle physics program. As a meeting focused on strategy, no proposals were presented nor reviewed.

The main focus of this meeting was to examine the planned evolution of the laboratory program in view of the report "*Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context"* released in May 2014 by the Particle Physics Project Prioritization Panel (P5). The P5 report has gained unprecedented support from the US particle physics community and Fermilab is playing a critical role in its implementation, with involvement and leadership roles in all the Science Drivers that P5 has identified. The PAC endorses the initiative by Fermilab to advance the internationalization effort for LBNF in line with the recommendations of the P5 report.

The Committee thanks the Fermilab Director for reporting on the overall status of the Laboratory programs and key issues facing the Management. The PAC was highly impressed with the development of the Master Plan & Campus Strategy that includes an Integrated Engineering Research Center (IER), consolidating the entire life-cycle of research, engineering, fabrication, and operations expertise for accelerators and detectors into one central geographic area. The committee was enthusiastic about plans for a future hostel, which is a critical component of an international facility.

The PAC thanks Steve Geer for organizing excellent presentations that have allowed the PAC to respond to charge that covered the following:

- Alignment with the P5 Plan
- Evolution of the process
- The future neutrino program
- Alignment of the particle-astrophysics program

The committee is pleased that the positions of Deputy Director and Chief Operating Officer have been filled in a timely way. The appointments of Joe Lykken and Tim Meyer considerably strengthen the laboratory leadership team. Finally, the committee would like to thank Hema Ramamoorthi for her logistical support.

Alignment with the P5 Plan

The PAC is pleased with the fast progress made by Fermilab leadership in aligning the priorities of the Laboratory with the vision for particle physics in the US outlined in the P5 report.

The P5 report recommends two muon experiments at Fermilab: g-2, to accurately measure the magnetic moment of the muon, and Mu2e, to look for charged lepton flavor violation through muon conversion to an electron in the presence of a nucleus. Although some technical challenges remain, progress has been made in the last year including the construction of the new building to house the g-2 experiment and completion of the solenoid reference designs for Mu2e. Both experiments are currently seeking CD2/3 approval.

The P5 report identifies the LHC and its upgrades as the highest-priority near-term large project. This project offers unique physics opportunities addressing three of the main science Drivers (Higgs, New Particles, and Dark Matter). As the host laboratory for the US CMS community, Fermilab is leading both Phase-I and Phase-II upgrades of the CMS detector. In addition, Fermilab is leading the accelerator R&D effort to develop Nb_3Sn focusing quadrupoles required to reach the ultimate luminosity at the LHC. The PAC was pleased to hear that the laboratory has taken steps to strengthen its CMS effort, including redirecting existing Fermilab staff to the CMS project as well as hiring senior scientists from the outside. The PAC notes that the laboratory management is taking steps to fill, in a timely fashion, the position of US CMS operations manager, which will be vacated when Patricia McBride becomes the head of the Particle Physics division.

The P5 report recommends developing international short- and long-baseline neutrino programs hosted at Fermilab. In particular, the long-baseline oscillation experiment is identified as the highest-priority large project in its time frame. During the past few months Fermilab's top priority has been to re-align its neutrino program with the P5 recommendations. These activities are described later in our report.

Fermilab has also taken steps to align detector and instrumentation R&D with near term high priority projects recommended by P5. In particular, liquid argon R&D has been redirected to be within the short-baseline neutrino program. In addition, an R&D effort directed toward the CMB program was initiated through the lab LDRD program. Continued R&D in high-field Nb_3Sn dipole magnets is crucial for future hadron colliders and for the US to maintain its leading role in magnet technology.

The PAC notes that a recent breakthrough in superconducting cavity R&D for the ILC was achieved. It is hoped that this new technique would lead to an increase in Q-value by a factor of 2-4.

The P5 report recommended a reassessment of MAP and early termination of MICE. Fermilab has taken steps to move as quickly as possible to comply with these recommendations. The MAP program will ramp down immediately with some parts potentially moved to the GARD program. The ramp-down of MICE involves negotiations with the international partners. The PAC is supportive of the priority given to keeping in the field the very talented young scientists currently involved in these projects.

Changes in the Fermilab management structure

To better handle the challenges ahead, the laboratory has made changes to its management structure. In response to the prominence of the neutrino program at the laboratory a new Neutrino Physics Division, led by Gina Rameika, has been created. Previously neutrino experiments were housed in the Particle Physics Division. The PAC notes that the separation into two divisions may lead to gray areas and competition for resources, and advises the Fermilab management to pay attention to these issues. Mike Lindgren has been appointed Chief Project Officer. This position was created in response to the increased number of projects at Fermilab. He is responsible for the successful execution of projects and will provide an additional force in the laboratory to ensure that projects get the resources they need.

Proton Improvement Plan

The Proton Improvement Plan (PIP and PIP-II) is crucial for the success of the Fermilab neutrino program. The status of the Booster refurbishment program was presented. The PAC shares the concern of the laboratory with the rate of refurbishment and the extension of the lifetime of the RF cavities. In addition, the PAC is concerned with the slow progress in increasing the POT to the NUMI beam. This is due to unexpected losses that limit intensity and slower than expected progress in implementing slip stacking in the recycler. Resolving these problems is critical for the success of the NOvA experiment.

The PAC recommends that laboratory management continues to pay close attention to these problems and calls a meeting of the Accelerator Advisory Committee to review technical progress towards achieving the NUMI beam goals.

Evolution of the Process

The formation of National Scientific Program Advisory Subpanel

Andrew Lankford, the HEPAP Chair, presented draft concepts for a possible National Scientific Program Advisory Subpanel (NSPAsP) to assist DOE and NSF in managing a national particle physics program. This national program includes experiments that are naturally reviewed by the Fermilab PAC, but also experiments that are not.

The PAC has concerns about the formation of a NSPAsP. The PAC agrees that a NSPAsP could add transparency and consistency in balancing a diverse set of facilities and experiments. Such a subpanel could provide mechanisms for the following:

1) Review proposals that are not hosted by a national laboratory. This could ultimately help DOE/NSF to enable a path to the CD process for such proposals.

2) DOE/NSF to reconsider programs that encounter unexpected budget overages and/or unanticipated technical challenges. This could provide an opportunity to mandate project re-scoping and/or cancellation.

3) Evaluate the overall financial and strategic balance across the programs and between laboratory-hosted and independently sited programs.

#1 describes a "normal-course" proposal review process for experiments that are not hosted by national laboratories, which does not currently exist. #2 addresses extraordinary circumstances where a program or the portfolio of programs has not evolved as planned. The P5 process has been used to address #3.

The PAC is very concerned that, in the case of "normal-course" review of experiments hosted at Fermilab, the relationship between a NSPAsP and the Fermilab PAC is not clear and could be potentially redundant and damaging, adding another hurdle to the timely and efficient approval of worthwhile projects.

In that normal-course review, the Fermilab PAC assists the Lab by providing timely advice on any proposal brought to it by the Director. The tradition of openness to proposals is many decades old and has generally served the community well. The threshold for obtaining a hearing in front of the PAC is generously modest. This encourages creative formulation of new ideas and often is a way for younger scientists to have an early impact. It is an iterative process.

Because the Fermilab PAC meets about twice a year, over time its membership forms a working knowledge of lab capabilities, strengths, and schedules. This understanding is not only crucial to provide a critical evaluation but also encourages programs as they are forming. A NSPAsP, if formed, would replicate the function of the Fermilab PAC without the advantages that result from the regular and extensive contact of the Fermilab PAC with the laboratory.

The PAC believes that the concept of a NSPAsP should be carefully evaluated in order to avoid delays due to an additional review which could be detrimental to the timely mounting of experiments at Fermilab. In addition, the PAC believes that the Director of the laboratory is in the best position to approve experiments, allocate resources, and avoid extraordinary circumstances (#2) with the advice from the Fermilab PAC.

The Fermilab Approval Process

Steve Geer reviewed the Fermilab approval process as outlined in the *Procedures for Researchers.* The traditional steps along the road to a running experiment include:

1) A recommendation by the PAC to the Director that he/she grant "Stage I Approval."
2) If that advice is accepted, laboratory resources are released to undertake initial studies of technical feasibility and to evaluate the experiment's fit within the laboratory's capabilities. Approval also initiates the process of drafting a Technical Scope of Work (TSW) agreement between the laboratory and the experiment's proponents.
3) Following more detailed evaluation, the proposal is supplemented to include preliminary engineering, detector design, beamline characterization, budget formulation, and institutional contributions. The proposal is then resubmitted to the PAC for possible "Stage II" approval.

This latter step (#3) generally requires a significant effort, and approval at that stage should be sufficient to initiate funding, construction, and a commitment for beam.

The laboratory has asked whether the traditional path is appropriate given the reality of the Critical Decision process required for projects greater than $10M in capital equipment. It was also observed that the Stage II process has not been followed during the past two years of Snowmass and P5 preparation.

The PAC understands that the CD process has changed the situation. But the PAC believes that a follow-up review akin to Stage II is still a worthwhile step and recommends that Stage II be modified in the following ways.

1) Stage II approval should be initiated by the Director, not the proponents.
2) Stage II should occur as soon as significant technical and organizational issues appear to be sufficiently resolved, but the level of detail should be much reduced from the previous Stage II threshold. One would expect less than a year for this step.
3) Stage II approval should mean that the Laboratory is prepared to support this experiment and that the proponents are prepared to accept the initial running conditions and support levels outlined in a draft of the TSW.
4) Furthermore, Stage II approval by the PAC and agreement by the Director signals that the experiment is ready to proceed to the CD-0 stage.
5) This step should not divert from efforts that would eventually lead to CD-0 preparation. Of course if the budget of a project is below threshold for the CD

process, granting of Stage II approval should lead to a TSW document followed by construction and beam allocation.

Recommendation of Stage I approval suggests that the PAC anticipates success of the proposal, but lacks sufficient information for full approval. Appearing one more time before that committee that knows it best allows the PAC to compare its original assessment with a more concrete realization of how the experiment might take shape. This is important closure and this final approval signals to the community and the agencies that the laboratory, the proponents, and the PAC are all prepared to support the experiment.

The future neutrino program

Short Baseline Neutrino Program

The Short Baseline Neutrino (SBN) program task force, consisting of representatives from the LAr1ND, MicroBooNE, and ICARUS collaborations headed by a newly-appointed SBN program coordinator, presented a status report on defining the SBN program. The report included studies on optimizing the baseline of LAr1ND, inter-detector correlations of systematic uncertainties in neutrino flux prediction, backgrounds arising from photons induced by cosmic rays within the beam spill, and possible optimizations of the horn/target configuration towards defining a "baseline" configuration. The committee also received a useful note from Prof. Carlo Rubbia calling attention to some important technical issues concerning cosmogenic events in LAr detectors. The committee greatly appreciates the collaborative effort between the three experiments towards defining and optimizing the SBN program; these are clearly in line with the P5's Recommendation 12: "In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab". The committee was also very pleased to hear of the commitment of CERN to refurbish and transfer the ICARUS T600 module to Fermilab.

The committee also heard an overview the physics context for the SBN program, including a separate report commenting on recent developments in interpreting the excess of events consistent with electron neutrino interactions at MiniBooNE. The importance of resolving the MiniBooNE excess has not changed with recent developments, and the Fermilab program is a critical element in the global program to understand the "short baseline anomalies". The proposed three-detector configuration would provide a valuable enhancement to the MicroBooNE programme to collect a large sample of LAr events to develop and test automated reconstruction algorithms, improve our understanding of neutrino interactions in LAr, and search for phenomena outside the conventional 3-neutrino picture.

The committee notes that the burden of proof for any claim for observing neutrino oscillations associated with sterile states is very high. Furthermore, a definitive program must be able to provide robust conclusions if the excess is due to unknown photon production mechanisms or deficiencies in our understanding of neutrino-nucleus interactions. The committee would like to see a detailed analysis of the added value of the three-detector program for clarifying the accelerator anomalies that some interpret as evidence for sterile neutrinos. This analysis should not only be in terms of sensitivities to a 3+1 scenario, but should also include a discussion of what would be learned in more general terms by having all three detectors in scenarios where, for instance, MicroBooNE has observed an excess of photons, an excess of electrons, or no excess whatsoever by the start of data-taking of the other two detectors.

The committee also appreciates the first steps towards a rigorous sensitivity study that are the basis for demonstrating the robustness of the proposed program. As this effort proceeds to a full proposal, the following uncertainties and issues and their impact in interpreting an excess of photons or electrons and the ν_μ disappearance analysis should be studied and quantified in detail:

- neutrinos produced from out-of-target particle production that may introduce significant differences in the neutrino flux at the near and far sites.
- detector performance and systematics, including those arising from the differences between the three detectors.
- neutrino cross sections and interaction modeling
- cosmogenic backgrounds, including coincident cosmic muons and neutrons.
- beam-induced neutrons.

We also emphasize the importance of further understanding the performance of LAr detectors in developing a robust case for the SBN program. This requires the maturation of fully-automated reconstruction algorithms as well as a program of control samples to directly verify the expected detector performance and mitigate cross-calibration issues associated with the differences of the three detectors. These developments are essential also for the LBNF program. As mentioned above, the committee also received comments regarding the difficulty of handling cosmic background occurring outside of the beam spill but within the drift time, which may have a significant impact on detector efficiencies. These issues should also be fully studied and addressed.
The committee also notes the following issues:

- The coordination of the LAr1ND construction and ICARUS installation presents a schedule risk. The laboratory should ensure that the appropriate coordination is in place, either through the SBN program coordinators or other appropriate mechanism. The role of NESSIE should also be clarified.

- The three collaborations have yet to reach an agreement regarding access to data from the three detectors or coordinating the overall analysis effort. A formal plan towards this end should be developed before the proposal is submitted.
- With the differing detector technologies in the SBN program and uncertainties in the configuration of the LBNF detectors, the alignment of the R&D effort for the SBN program with the LBNF is uncertain and should be further clarified. The relation to other LAr R&D efforts at Fermilab and elsewhere should also be articulated.
- The Booster Neutrino Beamline is currently minimally instrumented with effectively no monitoring downstream of the production target. The need and benefit of additional appropriate instrumentation should be considered.

The committee recommends that Fermilab assists the collaborations in tackling the above issues by providing necessary resources and manpower, including consultation with outside experts and facilitating further cooperation and collaboration between the three experiments. MicroBooNE is already funded and proceeding, and CERN has provided resources through the WA104 project to refurbish and move ICARUS, so the PAC would be pleased to see Fermilab provide resources for LAr1-ND detector R&D (which has now received NSF funding) to move ahead (perhaps by designating it a Test experiment) in preparation for the submission of a proposal.

Long Baseline Neutrino Program

The recent P5 report endorsed Fermilab's plan to build a world-leading neutrino program: "In collaboration with international partners, [the US should] develop a coherent short- and long-baseline neutrino program hosted at Fermilab." For the long baseline program, P5 emphasized that a change of approach was required: "The activity should be reformulated under the auspices of a new international collaboration, as an internationally coordinated and internationally funded program, with Fermilab as host. There should be international participation in defining the program's scope and capabilities. The experiment should be designed, constructed, and operated by the international collaboration." The laboratory has embraced this recommendation, and is working to establish the necessary collaboration.

Many activities are on-going to set up an international long-baseline neutrino program based at Fermilab. These included the development of the ICFA Neutrino Panel vision for an International accelerator-based Neutrino Programme (IabNP) and an International Meeting for Large Neutrino Infrastructure in Paris. The Laboratory recently hosted an international summit, led by Long and Roser, to initiate the process of establishing a new international collaboration. At this summit, it was agreed to form three working groups to evaluate the potential physics impact, cost, and schedule of different experimental

options. The participants agreed to establish an Interim International Executive Board to help form the collaboration, deliver an LOI, and guide development of a CDR. This interim board, which will be formed by the ad-hoc funding agency/lab director group, will be superseded by collaboration governance as soon as the collaboration is formed.

The PAC strongly supports the Laboratory-initiated process. We believe that the working groups, which will involve the worldwide neutrino physics community, will help to achieve a common understanding of many issues (e.g., baseline, beam energy, and detector optimization), and will help formerly competing groups to begin real collaboration. Ultimately, the PAC is hopeful that this exercise will result in an enhanced experiment and stronger collaboration. The PAC looks forward to a Letter of Intent from the new collaboration, and a conceptual design report during 2015.

The PAC acknowledges the enormous scientific and technical work of the LBNE and LBNO Collaborations and the substantial efforts made to expand international participation in the project.

Alignment of the particle-astrophysics program

The P5 report and the DOE/NSF announcement of the selected G2 Direct Dark Matter Detection Experiments have implications for the Fermilab Cosmic Frontier program.

P5 endorsed a cosmic microwave background program which should lead eventually to a very ambitious "Stage 4" telescope deploying half a million detectors in a single focal plane. The principal long-term goals of this program will be to characterize B-modes created at the end of the epoch of inflation and provide a cosmological measurement of the number of neutrino flavors and their aggregate mass. (A recent detection of the B-mode signal using the BICEP-2 experiment is a testimony to the rapid gains in sensitivity despite the controversy surrounding its association with inflationary B-modes.) The Particle Astrophysics program is already investing in this exciting area through collaboration on the South Pole Telescope. The PAC supports the proposal to grow this program at Fermilab.

Fermilab has also led the highly successful Dark Energy Survey which is now starting to produce results. The next step is to build an accompanying spectrograph - DESI - and this too was endorsed by P5. Fermilab is already a part of the DESI collaboration and, if and when the instrument is funded, Fermilab should expect to be responsible for a significant part of it. To engage in the longer term dark energy program, Fermilab has now joined the LSST Dark Energy Science Collaboration and is contributing to the software. LSST is expected to start construction very soon and to be in full operation by the end of the decade.

The G2 direct dark matter down-selection has chosen Super CDMS, LZ and the ADMX axion detector. Fermilab is joint lead laboratory (with SLAC) for the first of these and is planning to increase its presence in it. Fermilab scientists have also started exploratory discussions with the LZ and ADMX. Darkside, DAMIC and COUPP/PICO will continue to take data and be supported to the extent possible as R&D efforts.

Finally the holometer, which seeks evidence for fluctuations at the Planck scale, is now taking its first data and congratulations are in order. The measurement is photon shot noise-limited and it should be possible to detect a signal, if present, within a year. Such a result would surprise most theorists and open a new area of investigation.

The Center for Particle Astrophysics is to be commended on its recent accomplishments and the speed with which it has re-aligned its program to take advantage of new opportunities. At the next meeting the PAC would like to receive a complete report on the evolution of the long-term planning including an assessment of leadership and supporting roles in the different programs and how the whole forms a unified effort, especially given the national priorities.