Fermilab Physics Advisory Committee Meeting
November 10-12, 2016
Comments and Recommendations

Introduction

The Physics Advisory Committee (PAC) met at Fermilab to consider the Fermilab program and its alignment with the recommendations in the Particle Physics Project Prioritization Panel (P5) report: "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context." In this meeting, the PAC was asked to comment on issues that have emerged since the summer meeting and that are important to the success of the neutrino program, namely, the desirability of providing increased proton intensities for NOvA, the status of LBNF and the protoDUNEs, and a proposed "Run 3" for LArIAT. In addition, the PAC was asked to comment on three other areas in which there have been significant developments during recent months: plans for the laboratory's contributions to the CMS Phase 2 upgrade, the potential of a significant role for the laboratory in the ADMX experiment, and the lab's testbeam program.

During the executive session, the PAC discussed the possible timescale for the next long-range planning process for the community ("Snowmass / P5"). Joe Lykken presented a possibility of the Laboratory calling for expressions of interest roughly two years before the start of such a planning process, followed by submission of letters of intent about 6 months later. The PAC supports such a plan, and believes it would help both the Laboratory and community develop new ideas for the "P5"-process.

Also during the executive session, the PAC heard a brief presentation on the Laboratory's LDRD program. This program, which began in 2013, has been used to support a wide variety of new initiatives across the Lab divisions. The PAC commends Fermilab on the effective use of this program to seed exciting research opportunities. In this time of heavy project activity, the PAC agrees that the LDRD program plays an important role in maintaining the intellectual vitality of the Lab. The PAC looks forward to future updates on the scope of LDRD-supported activities.

The Committee thanks all of the presenters for their excellent reports and interesting discussion. We also thank Steve Geer and Hema Ramamoorthi for their usual flawless support of the PAC meeting.

NOvA

The fact that θ_{13} turned out to be large opened up several exciting opportunities for the NOvA experiment. Not only can the experiment observe $\nu_\mu \rightarrow \nu_e$ oscillations - already accomplished - it has the opportunity to provide decisive information on the very important question of the neutrino mass ordering, and on the potential deviation of the θ_{23} mixing angle from maximal. NOvA can also provide very important hints concerning the status of CP-conservation in the lepton sector and has the potential to uncover evidence of more new physics in the neutrino sector. All of these results will qualitatively modify the way we understand neutrinos and enhance our understanding of fundamental physics. The NOvA results, especially the hint for non-maximal θ_{23}, were among the most influential shown this past year at the Neutrino 2016 Conference, and we congratulate them on such a significant milestone.

NOvA's ability to reach all these exciting goals is proportional to the amount of data it accumulates. Access to more statistics may translate into robust discoveries and will help pave the way to a very exciting next-generation program. Access to more statistics in a timely fashion may allow NOvA to be the first among all the current and near-future experiments - including T2K, JUNO, and ORCA - to reach the next important milestones in neutrino physics.

The PAC, therefore, believes it is very important to seriously consider increasing the number of protons-on-target to NOvA. This increase can be achieved by extending the NOvA run or increasing the beam power. Incremental improvements to the accelerator complex (booster and main injector) at a modest cost could be made in the next several years in order to increase the beam power by as much as 20%. These improvements are largely part of PIP-II and hence can be interpreted as an acceleration of the PIP-II plan. We strongly encourage the Lab to explore these possibilities.

LBNF and ProtoDUNEs

The committee received updates on LBNF and the protoDUNEs, and a report on the recent LBNC meeting from the LBNC chair. The committee would first like to offer its congratulations for the successful award of CD-3a approval for the LBNF far site construction, a highly significant milestone in the development of the project. The committee is impressed with the progress on LBNF and endorses the conclusions of the LBNC concerning LBNF. In particular, we would like to congratulate the beam optimization task force for showing how a beam with significantly greater capability could be designed, but we agree that further optimization of the beam design needs to be coupled to engineering design and cost considerations. We would also like to make special note of the concerns of the LBNC on the progress of analysis of the

impact of various near detector designs. The analysis is currently unable to demonstrate any realistic difference in sensitivity between the three designs, which seems implausible, and therefore is not yet an adequate tool for distinguishing among proposed designs. LBNF/DUNE management is encouraged to consider whether further resources are needed to make sure these tools are ready in a timely manner, or whether alternative methods should be developed to decide on near detector design.

The PAC considered the goals and schedules of the protoDUNE detectors. The first main goal of protoDUNE SP is to do engineering risk mitigation for the DUNE far detector in preparation for its CD2 review by stress testing the production and QA of detector components, their installation procedures and interfaces, and the validation of detector design by operation with cosmic rays. The committee endorses the importance of this goal, and points out that the value of the project towards far detector CD2 is enhanced by maximizing the similarity in its design to the far detector design and the use of common components. In fact, the cold electronics will not be the same, and the project should strive to minimize further differences.

The second main goal of protoDUNE SP is to provide critical calibration data by measuring the response of the detector to test beams of protons, pions, muons, electrons, etc. The committee agrees that such data are of great importance to DUNE, and that there would be significant benefits to the momentum and international reputation of the collaboration if such data could be obtained before LS2. However the committee feels that if a conflict arises between the two goals described here, the first goal of providing the clearest possible technology demonstration prior to CD2 should take priority, as the calibration data could be taken after LS2 without having a serious impact on the science return of DUNE.

The committee also heard about progress towards protoDUNE DP. There has been impressive technological progress in the development of this alternative design. The goals of protoDUNE DP are to demonstrate the performance of the dual phase technology and establish it as a possible technology choice for future far detector modules, and also to obtain similar test beam calibration data as for protoDUNE SP. The committee feels that the protoDUNE DP team is on track to meet these goals.

The committee also discussed the most critical of the recent LBNC recommendations and endorses them. The PAC would like to emphasize once again the importance of understanding personnel allocations, in particular in connection with other LAr efforts. On a related point, the PAC notes that automated analysis of LAr data seems to be becoming more widespread and routine. In light of that the committee would like to see an update at the next meeting of progress of the three SBN experiments at adopting a common analysis framework, which we believe is essential to achieving their physics goals.

LArIAT

The Committee heard about the current status of the LArIAT test beam program and its proposal for a third run to investigate the impact of wire pitch and test the ARAPUCA light collection system. The Committee congratulates LArIAT on a steady stream of achievements, including detector studies such as the impact of N_2 contamination and the study of scintillation from electrons from muon decay-at-rest, and physics studies such as muon capture on argon and preliminary pion-argon cross section measurements.

1. *Is the proposed LArIAT Run 3 program unique and well motivated scientifically?*

The proposed program is well-motivated. In particular, the pitch study demonstrates an important and unique measurement that can be performed at LArIAT due to the small and flexible platform. Likewise, while ARAPUCA will also be part of protoDUNE, LArIAT Run 3 offers a valuable opportunity to perform initial tests in a smaller and dedicated study.

ii) Is the proposed LArIAT Run 3 program well aligned with the needs of DUNE and the LAr neutrino community.

As a small-scale prototype, LArIAT is able to make changes relatively quickly, allowing tests of different technology choices that can be used in upcoming LAr-TPCs, for example the interesting tests of wire spacing, or early tests of the ARAPUCA light sensors. The test-beam measurements themselves are also an important part of the LAr program, as they are the only measurements of charged-particle interactions in LAr at the relevant energies for DUNE and the SBN program, until protoDUNE gets beam. In addition, the experience gained with analyses of test-beam data will be directly relevant to what is needed for protoDUNE. LArIAT will be able to study the sensitivity of interaction cross sections to detector systematics, such as changes in argon purity, electronics response calibrations, and energy scale. The PAC feels it would be valuable for the LArIAT collaboration to provide the Lab with an explicit roadmap of how their effort will best be integrated with the upcoming measurements with protoDUNE, the SBN program, and DUNE.

iii) Is it likely that a continued LArIAT effort will take important effort away from the
protoDUNE activities?

Continuing effort toward a LArIAT Run 3 will have little impact on the construction schedule for protoDUNE. Although the intellectual resources going into the LArIAT analyses could be very useful to the protoDUNE effort, given how limited in personnel those efforts are, the PAC feels that those analyses should (and are likely) to go forward independent of a Run 3. Therefore while in principle immediately

redirecting that intellectual effort toward protoDUNE could advance the protoDUNE measurement program, in practice this would mean losing the valuable results from LArIAT's existing data sets.

CMS Phase 2 Upgrade

The PAC was asked to comment on the current situation and on the progress being made towards the laboratory's contributions to the CMS Phase 2 upgrade.

The activities of the Fermilab scientists in CMS were reviewed at the June 2016 PAC meeting and were found to be strong and visible by the Committee. The PAC recommended that the group's role in scientific computing be increased further.

The LHC and its experiments entered a vigorous upgrade program to meet the challenges of the High-Luminosity LHC scheduled to start data taking by 2026/2027. The aims of this upgrade are well defined and agreed upon in the international CMS Collaboration as a major investment to the future successful operation of the detector. The role of Fermilab's CMS group as one of the leading groups in CMS is reflected also in the major involvement and resources committed to the upgrade.

The Committee heard a report by Fermilab's Vivian O'Dell, who serves as the US-CMS HL-LHC Upgrade Project Manager. Fermilab plays a leading role in the R&D and construction of the new Outer Tracker, including the effort on the pixel readout chip as the only US member of the international RD53 collaboration, the innovative and challenging High-Granular Endcap Calorimeter (HGC), fast timing system developments, the Trigger / DAQ upgrade (including the new level-1 track trigger), and the Project Office. The PAC remarks that FNAL has taken major financial responsibility and risk of the HGC project and currently plays a leading role in the technical coordination of the project. The PAC would be pleased to see Fermilab position itself as a natural candidate to play a similar role in the upper management of the project.

The PAC commends the Laboratory for its continuous leadership in the CMS Collaboration, which is also reflected by its important contributions to the HL-LHC upgrade. The group focuses on the developments and procedures needed for the upcoming system TDRs. Continuous support of the Laboratory's engineering staff and the Project Office is needed to meet the project schedule. The TDRs of the international CMS collaboration are expected during CY2017, except for the Trigger-DAQ TDR, which will be delivered later. The EDRs and start of construction are scheduled for CY2019/2020. The US-CMS schedule foresees DOE CD-1 by the end of 2017, and CD-2/3 by early/mid 2019. The NSF timeline for the PDR/FDR is similar. The PAC looks forward to these milestones being met, as they are critical for the success of CMS International in view of the HL-LHC.

Axions

The existence of dark matter is supported by an overwhelming weight of indirect evidence. The nature of dark matter, however, is still unknown. The two major particle physics candidates for dark matter are axions and WIMPs. The committee heard presentations describing the DOE-supported ADMX-G2 experiment, led so far by the University of Washington. In view of the difficulties in completing construction and commissioning of ADMX-G2, the effort was recently descoped by DOE to cover the limited range of frequencies 0.6-2.0 GHz. Exploration of the range 2-10 GHz, part of the original ADMX-G2 proposal, is not funded and will be reconsidered after consolidation of results from the exploration in the range up to 2 GHz.

Fermilab scientists had joined ADMX-G2 in 2014 with a limited role and no management responsibilities. They carried out a successful R&D program focused on enabling searches at higher frequencies, up to 10 GHz with novel cavities, and beyond 10 GHz with quantum nondemolition detection methods under development for quantum information processing applications. They made a clear and compelling case for future R&D in the areas of high-Q, tunable, superconducting RF cavity development (already underway with Fermilab LDRD support), and in the development of the quantum nondemolition technology. Some of this work is already being carried out as a Fermilab-UChicago project, partially supported by a successful Fermilab LDRD project and by private funding from the Heising-Simons Foundation.

In view of the difficulties with ADMX-G2, the Collaboration and its lead institution, the University of Washington, have requested that Fermilab accept the role of lead laboratory for the current ADMX-G2, taking over project management and a limited set of technical tasks.

The Committee believes that the science case of axion searches is very strong and matches the mission and technical capabilities of Fermilab. Additionally, the technology development activities are at the cutting-edge of research and, if successful, will lead to important applications in several areas. There are exciting synergies with areas relevant to quantum sensing and information. Overall, the investment from the Lab side would be modest with significant potential return, although the risk cannot be properly assessed in the absence of more detailed information.

The PAC supports the envisaged, limited management role of Fermilab for ADMX-G2. The resulting technical burden appears to be minimal even though the experiment is at a remote site. That said, the PAC notes that the shift of control of financial commitment of ADMX-G2 to Fermilab arises from financial stresses within the project, which are cause for concern.

The PAC also supports next-generation R&D activity for possible future high-frequency experiments. The science motivation is good, as is the match to Fermilab and broader Chicagoland capabilities. Future investments, however, will need more careful evaluation.

Test beam

The PAC was asked, based on the findings of the FBTF Committee, to comment on the importance of continued FTBF operation and the desirability of enhancing the facility.

The PAC heard a presentation on the findings of the Fermilab Test Beam Facility (FTBF) Committee that reviewed the FNAL test beam program. The FTBF is one of three facilities worldwide (CERN Switzerland, Fermilab, IHEP-Protvino Russia) delivering high-energy primary proton test beams. These are crucial for new detector developments as demonstrated by the results presented. The FBTF, which currently has two beam lines for short and long-term users, serves a large and diverse user base, including many users from ongoing Fermilab projects. Good and constantly improving infrastructure, tools for beam characterization and central data acquisition are available. Improved application procedures for beam time along with the dedicated effort of a small but very efficient team of Fermilab staff scientists, as well as flexibility among users, have so far allowed accommodating all test beam requests. Importantly, a peak of requests is expected during the upcoming 2019/2020 proton injector technical stop at CERN and parallel ongoing LHC upgrade R&D.

The PAC commends the Laboratory and especially the dedicated FTBF staff for the success of the FTBF program since its start in 2005, and supports the continuation of the FBTF operation. The FBTF represents a very valuable resource for the HEP community with significant impact on ongoing and future R&D for a relatively small investment. It is also a unique training facility for students and postdocs. The PAC agrees with the findings and recommendations of the FBTF Committee. A small increase in dedicated FTE and M&S support would allow to further increase the high impact of the FBTF on the HEP program. The PAC suggests that all FBTF work be accompanied by a registered FNAL report to maintain a record of the program.