Fermilab Physics Advisory Committee Meeting
January 15-17, 2015
Comments and Recommendations

Introduction

The Physics Advisory Committee (PAC) met at Fermilab to consider the Laboratory's scientific activities and their 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*". The Committee thanks the Fermilab Director and Deputy Director for reporting on the overall status of the Laboratory programs and key issues facing the Management. The PAC is pleased with the thoughtful enunciation of Fermilab's goals and its determined focus on organization. For the first time, an explicit vision and mission have been succinctly been stated: the overriding mission being "to do great science" which the PAC vigorously applauds. The six themes nicely encompass the will of the community and match the P5 recommendations: Neutrinos, LHC Contributions, Cosmic Program, Explore the Unknown, Accelerator Science, Projects and Facilities. The PAC was pleased with the analysis of how each theme should evolve during the next decade. They are clearly described and set benchmarks that make scientific and strategic sense. The PAC also appreciated the explicit articulation of point-by-point goals for the neutrino program over the next three years. These goals are aggressive, but necessary in order to achieve their 2025 targets.

Fermilab is positioning itself to take on a new role as host for at least a thousand neutrino physicists as the world's central neutrino program–an international responsibility for neutrino physics similar in scope to CERN's responsibility for proton collider physics. This mandates a new approach to the management of a U.S. facility. The Laboratory management team is settling into a sensible new structure, and cultivating support in the Department of Energy and the community, and is clearly aware of how complicated this evolution will be.

A most welcome aspect of the international collaboration is the strong technological and strategic partnership with CERN towards liquid argon R&D. The realization of the CERN neutrino platform and the associated program with charged particle beams complements the Fermilab neutrino platform, which exploits neutrino beams. This CERN effort promises to have a very significant impact on the neutrino program at Fermilab. The PAC encourages Fermilab to continue strong coordination and cross-fertilization of the liquid argon R&D carried out at the two laboratories. The PAC

acknowledges the support by the US NSF, the Italian INFN, the UK STFC, and other funding agencies that, in addition to the DOE, provide funding for, and eventual delivery of, crucial elements of the Neutrino Program at Fermilab.

The PAC congratulates the Lab on its improved and indeed, excellent scoring in the most recent Performance Evaluation and Measurement Plans evaluations by the Office of Science. An A^- score for Environment, Safety and Health is particularly noteworthy.

At this meeting the PAC considered one proposal and five letters of intent (LOIs). The most important discussions during this meeting focused on two major initiatives for the Fermilab neutrino program that have recently produced LOIs: (i) a new long-baseline experimental facility, LBNF, including the experiment and the associated accelerator facilities, and (ii) an expanded short-baseline program that goes beyond MicroBooNE. The Committee was asked to comment on the status of these efforts, the progress recently made, the alignment of these LOIs with the P5 Plan, and on additional actions that the Laboratory could take to strengthen these international collaborations.

Three LOIs for smaller neutrino efforts, ANNIE (P-1053), CAPTAIN-BNB (P-1060), CAPTAIN-MINERvA (P-1061) and one proposal NESSiE (P-1057) were presented and discussed by the Committee. For the NESSiE proposal, the PAC was asked to comment on its scientific goals and the technique proposed, while making comparisons with the competition, and outlining what was expected from Fermilab to make this experiment successful. P-1039, an update on the Drell-Yan Experiment with Polarized Target (SeaQuest extension), was also considered at this meeting.

The Committee heard a status report on NOvA, the Laboratory's present flagship experiment, and was asked to comment on its status and the optimal strategy for determining when NuMI should switch from neutrino to antineutrino running, given the latest expectations for proton delivery.

Reports dealing with other important aspects of the Fermilab program, including CMS at the LHC and its upgrade(s), and the Particle Astrophysics planning for the future were also presented.

The PAC heard a report on the status of the accelerator complex, PIP, and expectations for the coming years. Last year's accelerator performance was the 2nd best in the Lab's history, with 3.1E20 POT delivered to the NUMI beam. This impressive achievement was accomplished whilst the PIP program required two cavities removed from the Booster for refurbishment. The plan is to roughly double the annual POT for FY 2017, while also delivering protons for the BNB and the g-2 experiment. The PAC was particularly pleased to see the excellent progress on replacement of Booster RF cavities,

which is needed to enable this increase in beam delivery. They expect to have 17 refurbished cavities before the 2015 summer shutdown.

The Committee greatly appreciates the time and effort required of the proponents and presenters to prepare the excellent reports for this PAC meeting. In addition, the PAC thanks Steve Geer for the excellent organization and Hema Ramamoorthi for her logistical support.

The Neutrino Program

Future Long-Baseline Neutrino Program (LBN)

We congratulate the IIEB and its chair on the outcome of the successful and effective actions that delivered a LOI undersigned by a larger, more coherent, and more international collaboration.

We encourage all stakeholders to continue the effort for growth and internationalization of the collaboration with the same intensity and institutional oversight, without losing the current momentum. This is crucial for the success of a mission vital for the future of Fermilab and the international neutrino program.

The PAC strongly recommends formation of a Long Baseline Neutrino Committee (LBNC) to provide Fermilab with detailed review and oversight of the science, management, and technological choices of the LBNF/ELBNF program. The LBNC should operate in strong cooperation with the PAC. The LBNC Chair should serve as an ex-officio member of the PAC.

The PAC welcomes the sharply stated and well defined goal of the Fermilab leadership to prepared a full CDR in 2015 with the goal of constructing a first 10 kton module and start operations by 2021. Achievement of these important milestones requires a detailed assessment of the baseline parameters of the facility and the detector. In particular, it is crucial that a full integration of Fermilab and international engineering resources be soon achieved.

The PAC encourages the project office and the collaboration to rapidly address, through a series of reviews under the guidance of Fermilab and of the soon to be formed LBNC, the overarching questions that remain open and that may have a significant impact on the overall cost, schedule, and scope of the project. The list of questions includes but it is not limited to: the choice of the construction technique for the cryostat; size and shape of experimental caverns; size and shape of support caverns for installation staging and permanent services; strategy for argon procurement and delivery; mitigation of safety hazards and in particular of ODH; provision of egress paths and emergency exhausts. It is particularly important that the process fully integrates, from the beginning, an

assessment of the implications of each choice on safety.

We recommend that the forming collaboration immediately proceed to define and set up the Working Groups (WG) required to address the several open R&D questions. We request the forming collaboration to report to the next PAC and/or LBNC meeting on the progress of each WG, with special emphasis on the physics reach of the first 10 kton module. We also request the forming collaboration to provide, at the next PAC and/or LBNC meeting, detailed information on the collaboration's strategy and plans to explore in depth the possibility of achieving the required impressively small systematic errors. The excellent analysis of the sensitivity presented in the Short-Baseline Neutrino LOI should serve as a guiding standard.

Future Short-Baseline Neutrino Program (SBN)

The Committee was asked to evaluate the SBN program based on the following:

i) *We ask the PAC to comment on the current situation and on the progress being made.*
ii) *Is the initiative described in the LOI consistent with the P5 Plan?*
iii) *Are there additional actions the Laboratory should take to strengthen the collaboration/program-forming process?*
iv) *What should be accomplished before a full proposal (CDR) is submitted to the PAC for consideration and what would the Committee like to see included in the proposal?*

The Committee thanks the collaborations for the series of excellent presentations describing the scientific landscape for sterile neutrino searches, an overview on Liquid Argon (LAr) TPCs, sensitivity studies, and the current implementation plan.

We respond to each point in turn:

i) The Committee was greatly impressed with the progress on all fronts, first in the developments within each of the collaborations, second in understanding the implementation of the combined program of the three detectors, and finally in producing a robust estimate of the sensitivity of the proposed program. We were particularly pleased to see the fruits of the joint effort in assembling a coherent analysis framework in which to evaluate in detail the impact of neutrino flux and interaction modeling uncertainties, as well as backgrounds arising from cosmic rays and other sources.

ii) The P5 Plan issued two recommendations pertinent to the SBN program:
Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.

The Committee finds that the SBN program as described in the LOI is fully aligned with these recommendations. The Committee notes the fundamental contributions from the CERN, INFN, NSF, and STFC, as well as the significant participation from European institutions, which bring a significant international component to the program.

iii.) The Committee was encouraged by the high level of coordination across the collaborations exhibited by the LOI and congratulates the Short Baseline Coordinator and Task Force on the remarkable progress achieved since the summer. We encourage the Laboratory to consider either extending the task force or forming a similar oversight group to ensure continued coordination between the collaborations until more formal memoranda of understanding are established.

iv.) Several important questions and issues remain to be addressed:

a. A robust and reliable neutrino beam line is essential to the success of the program. The related issues of possibly significantly enhancing the neutrino flux through a two-horn configuration and other improvements to the target station were also discussed. We request that a full cost and resource estimate for the various proposed improvements to the upstream optics, installation of beam line instrumentation, and potential changes to the horn configuration, be prepared for the next meeting in order to inform which improvements should be implemented.
b. The SciBooNE hall, as an experimental area for placing detectors within a neutrino beam, is a precious resource. We encourage the Laboratory to fully explore the possibility of situating the LAr1ND cryogenics outside of the SciBooNE hall in its own enclosure, and to develop a program of small and short-term experiments and tests that can be performed in the SciBooNE hall. Generic infrastructure improvements (e.g. a crane and loading door and dock) that may facilitate the cycle of installation, commissioning, operation, decommissioning, and eventual removal of experimental apparatus should also be considered.
c. The three experiments will draw upon common engineering and technical resources from the Laboratory; furthermore they have a significant overlap

in collaboration membership, particularly between LAr1ND and MicroBooNE, and also with the LBNF effort. Careful coordination and planning will be required in order to ensure that these resources are deployed effectively and do not conflict. To this end, the Committee encourages the collaborations to develop an integrated "work breakdown structure" in order to facilitate coordination.

d. The deployment of three substantially different LAr TPCs in the program and the large differences in neutrino flux at each detector, presents significant challenges in understanding relative efficiencies and acceptances. This is further exacerbated by the nature of the sought-after physics, which changes the active neutrino flux at each detector, leaving potentially no "standard candles" in the beam itself. The collaborations are encouraged to develop a strategy of cross calibrations that will lead to an understanding and demonstration of these relative acceptances for the various event types at the 1% level.
e. The efficiency and background estimates continue to be based on truth-level studies. The collaborations, particularly MicroBooNE, which will confront data soon, should integrate the reconstruction and event classification algorithms into the sensitivity studies or otherwise demonstrate their current capabilities.

The Committee recommends Stage 1 approval for the SBN program, which incorporates LAr1ND and ICARUS with MicroBooNE towards a coherent SBN program. We recommend that the Laboratory provide the necessary engineering and technical resources to allow the program to move forward expeditiously, and to understand the scope of the Booster Neutrino Beamline modifications and improvements.

LOI UPDATE: P-1053 Atmospheric Neutrino Neutron Interaction Experiment (ANNIE)

The PAC was impressed by the progress being made by the ANNIE collaboration. The physics goal of measuring neutron emission in neutrino interactions in the BNB would be a valuable and important contribution, both for its direct physics benefit to searches for proton decay and supernova neutrinos, but also for providing another observable to constrain models of neutrino interactions. The development of LAPPD detectors, which the ANNIE project is helping to push forward, could be a major technological development with wide applications outside of particle physics.

The PAC therefore recommends that the ANNIE collaboration be granted Stage 1 approval and be supported to proceed with Phase I of their proposed work. They should

work closely with Fermilab staff to produce full costs and schedules for the planned experiment in preparation for requesting the next level of approval.

The PAC is recommending that the SciBooNE hall should be adapted into an effective site for small, rapidly mountable experiments in a neutrino beam. ANNIE would therefore have to use that space in an efficient manner. In light of this, the PAC would like the proponents to show a detailed plan as to how they would still achieve their physics goals in a timely fashion if the development of the LAPPD detectors suffers any significant delays, and to update the PAC at its next meeting on progress towards producing the necessary LAPPDs.

PROPOSAL: P-1057 ν_μ disappearance at FNAL-Booster (NESSiE)

The PAC thanks the NESSIE collaboration for the significant amount of work they have invested in producing a proposal to perform a search for sterile neutrinos by looking for muon neutrino disappearance in the BNB. The experiment would bring a strong and expert group of neutrino physicists to work at Fermilab, which would be a great benefit to the Laboratory as a world center of accelerator neutrino physics. The PAC has been asked to answer four specific questions concerning the NESSIE proposal.

i) Is the science in the proposal interesting and/or compelling?

The underlying science case is the search for sterile neutrino oscillations in an accelerator neutrino beam, i.e., the same physics goal as MiniBooNE and the Short Baseline Neutrino Oscillation Program, and hence is compelling. However, muon neutrino disappearance is not a direct test of the existing claims for the appearance of electron (anti)neutrinos, although it is interesting in its own right.

ii) Is the technique proposed appropriate for, and likely to be capable of, reaching the physics goals of the experiment?

The proposed method does seem appropriate for the goal of searching for muon neutrino disappearance, although the OPERA spectrometers are rather coarse for this energy range and therefore would not be the design selected if one were starting from scratch to design an experiment for this specific goal. The ability to do event-by-event charge identification is a significant advantage, particularly if the experiment is ever run in anti-neutrino mode. The PAC has no reason to believe that the experiment could not achieve the goals it has set.

iii) What is the competition for reaching the physics goals of the proposed experiment? Does the proposed experiment have particular advantages or disadvantages relative to the competition?

The main competition for achieving the physics goals is the SBN Program at Fermilab. That program is also sensitive to muon neutrino disappearance, although its claimed sensitivity is not as great as the claimed sensitivity of NESSiE. However the SBN sensitivity to electron neutrino appearance more than compensates for its lesser sensitivity to muon neutrino disappearance, and hence it is preferred if resource limitations do not permit both NESSiE and SBN to be pursued.

iv) What is needed to make such an experiment successful?

The demands on Fermilab to host this experiment may be very significant but have not been quantified. In particular, NESSiE as proposed would require occupation of the SciBooNE hall to the exclusion of other experiments for an extended period, and would require significant resources for installation and operations as well as for reconstruction of the OPERA spectrometers with new top/bottom yokes. None of the associated costs are known in detail. Of course an experiment seeking Stage 1 approval usually does not have accurate cost estimates, which are only generated after Stage 1 approval is given. However the NESSiE collaboration stated in their presentation that Fermilab must decide now whether to proceed with this experiment. Given the lack of knowledge of the level of resources that would be needed from Fermilab, the high level of demand already being placed on Fermilab technical and engineering effort by the long- and short-baseline neutrino programs, and the existence of a higher-priority experiment with partially competing science goals, *it is not possible for the PAC to recommend that NESSIE be approved at this time.*

CAPTAIN

LOI: P-1060 CAPTAIN-BNB

The collaboration proposes to run the CAPTAIN detector near MI-12 of the Booster Neutrino Beam. The goal is to measure the neutrino Argon cross sections to an accuracy of approximately 10% at neutrino energies around 10 MeV. This cross section has not been measured previously and theoretical estimates are uncertain to at least 15%. These measurements are directly relevant to the possibility of measuring electron neutrinos from a future supernova in the ELBNF detectors. Additional information for tagging supernova events will be gained by studying the event topologies and the details of low energy photons arising from cascade de-excitations.

LOI: P-1061 CAPTAIN-MINERvA

> The collaboration proposes to measure the inclusive and exclusive neutrino cross sections on Argon in an energy range (1-10 GeV) directly relevant to the Long Baseline Neutrino program. The detailed measurement of NC electron-like events can be compared to models. Furthermore, combination with other MINERvA data will allow detailed measurements of ratios of cross sections on Argon with measurements for other nuclear targets. This should result in improved theoretical understanding of neutrino nuclear cross sections.
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> The PAC is encouraged by the integration of the MINERvA and CAPTAIN collaborations in this proposal. The siting of the CAPTAIN detector in either the area of the present Helium target area or within the Minerva detector itself will provide these critical physics measurement.

The PAC strongly endorses the physics goals of the CAPTAIN-MINERvA and CAPTAIN-BNB initiatives.

The PAC looks forward to the collaboration's return with a full proposal. The PAC encourages the CAPTAIN collaborators to work with the Lab to come up with an engineering plan and schedule to accomplish both the BNB and MINERVA parts of their program. The CAPTAIN collaboration should also work to coordinate their efforts with the major collaborations of the SBN program.

LOI: P-1039 UPDATE: Drell-Yan Experiment with Polarized Target (SeaQuest extension)

The SeaQuest extension E-1039 aims at resolving the proton spin puzzle, and in particular measuring the Sivers function for sea quarks. E-1039 is planned to achieve a sensitivity level far superior to other experiments. The collaboration presented a very detailed and very well thought out plan for the transition from SeaQuest to E-1039. The case was successfully made that unique measurements could be made by E-1039 to complement those from experiments at other facilities, notably COMPASS at CERN. The PAC appreciates the opportunity offered by this proposal to continue the partnership between Fermilab and the nuclear physics community. We encourage the development of a TSW in preparation for Stage 2 approval, which will require an expectation of full funding from the DOE Office of Nuclear Physics.

NOvA

The PAC congratulates the NOvA experiment on receiving CD4 in September 2014, and on the successful operation of their detectors. The Collaboration is now taking data

routinely with the full detector and ~320 kW beam power. Both the detectors and the NuMI beam have been operating with extremely high efficiency. The near and far detector uptimes are greater than 95%, and the NUMI uptime (outside of scheduled shutdowns) has been 87%. The NOvA detectors are functioning well: the NOvA far detector has 99.5% of channels functioning, and 97.6% of the near detector channels are active. They have demonstrated acceptable levels of cosmic ray rejection. The Collaboration hopes to release the first ν_e and ν_μ results before the summer. The PAC looks forward to these results.

The Collaboration explained their current strategy for deciding when to switch from neutrino to anti-neutrino running. They would like to collect ~6E20 POT in neutrino mode, which would take approximately 2 years at the current rate of data collection. If the ν_e appearance rate in these data is consistent with expectations from T2K (given the unknown mass hierarchy and CP phase), they would switch to anti-neutrino mode. If the initial data show an inconsistency with T2K, they would take more neutrino data to clarify the situation. In addition, the Collaboration would be unlikely to switch to antineutrino mode if the beam power were significantly below 6e20 POT/year. The PAC supports this general strategy. It would be appropriate for the NOvA collaboration to present an update of their ν– $\bar{\nu}$ run strategy after another year of data taking.

CMS and USCMS Program

The PAC is pleased that the Laboratory is providing the necessary support to the CMS effort. The Committee acknowledges the leadership that Patty McBride has provided to USCMS and welcomes Lothar Bauerdick to the position of US CMS operations manager and Vivian O'Dell to that of Phase 2 Upgrade Project Leader. The Committee is especially pleased that the Laboratory has put already in place a strong leader to guide USCMS through the challenges of the upgrades for the HL-LHC.

The PAC heard a presentation describing past and current work on CMS and the planned CMS upgrades, including a very complete and detailed presentation on work for CMS Phase-1 and Phase-2 upgrades.

Fermilab has a large effort in CMS with more than 100 FTEs contributing, roughly half of whom are CMS authors. It hosts the LHC Physics Center (LPC) to provide a broad range of CMS expertise at one site, which is of great value for the broader USCMS collaboration. The PAC is very supportive of the LPC and its role within USCMS; it could serve well as a model for current and future neutrino experiments at the Laboratory.

The Fermilab group plays a key leading role in CMS covering the science drivers as well as the Phase-1 upgrades and the required R&D activities for Phase-2 readiness (taking

advantage of unique Fermilab facilities). Fermilab also hosts the US Tier-1 facility for CMS (largest of all T-1s). The PAC is impressed by the Fermilab efforts in Higgs physics, SM measurements, and searches for new physics.

An attractive science plan was outlined for Run 2, where supersymmetry results are the most widely anticipated in the run's early phases. Upgrade activities include FPIX, Tracker, HCAL, and Level-1 Trigger (jointly with universities). Fermilab is involved in all aspects of CMS computing, including both software and hardware. An important achievement is the evolution of CMS software to support a multi-threaded mode, significantly improving its memory footprint. Significant extensions of this type of work will be of key importance for Phase-2, where the computing requirements will increase by up to two orders of magnitude.

Particle Astrophysics Plan

The PAC heard a presentation describing progress reported in the recent Particle Astrophysics Strategic Plan. It notes that the plan is very well aligned with the recommendations of the P5 Committee and describes an exciting set of activities to advance the program over the next decade.

Fermilab has long supported several dark matter experiments and these have set impressive limits on different types of dark matter particle candidates. The DOE has recently selected three of these experiments -- ADMX, LZ and Super CDMS for support at the "G2" level. The plan is ambitious and involves making contributions to all three of these experiments as well as to retain Fermilab's connection with other efforts including DarkSide (which will be supported by NSF) for the development of technology to be used at the G3 level in the future. The PAC applauds the ambition of this program and believes that the proposed level of effort, roughly ten FTEs, is appropriate. It believes, however, that a better approach would be to evolve towards making larger technical contributions towards fewer experiments.

Fermilab should be proud of its leadership in the construction of the Dark Energy Camera and the ongoing execution of the Dark Energy Survey. Not only has this enabled an important investigation of the properties of dark energy, it has also created a cadre of scientists and engineers that is highly proficient in using optical telescopes, a tradition that began with Fermilab's involvement in the Sloan Digital Sky Survey. It is therefore somewhat of a surprise that the involvement in the next dark energy optical projects, DESI and LSST should be so modest. The experience that resides at Fermilab could contribute heavily to both DESI and LSST. In particular, DES is a direct precursor to LSST, and much of the experience being gained at Fermilab as part of the global DES effort will be very useful for optimizing LSST science.

There are strong indications that DOE will expand its presence in studies of the cosmic microwave background radiation and, in particular, that it will strongly support so-called Stage 4 experiments (CMB-S4). Because of the interesting science possible in cross-correlating optical and CMB survey information, there is an overall motivation to possess expertise in both of these areas (for which the theory group is well positioned). Fermilab has joined with ANL, LBNL and SLAC to help develop a nationwide collaboration for CMB-S4 and proposes to build up its experimental effort very rapidly to be of order 16 FTEs. The current activity, however, although highly relevant to upcoming Stage 3 experiments (SPT-3G) and of high quality, is quite small. Growing this rapidly to a large leadership role in the field in the presence of significant programs at three other National Labs and many universities will be challenging; properly defining a unique Fermilab program will therefore require a significant effort. Furthermore, considering that the combined FTE level in optical surveys and in the CMB is held flat in the proposed plan, there will likely be issues in manpower management as the technical expertise required in these two areas has very little overlap.

The PAC was glad to learn that the visionary holometer experiment is now making measurements and is eager to learn the results over the coming year. If these turn out to be null, then the experiment will have a successful completion and the associated group can move on to other experiments. If a significant quantum gravity effect is detected, then there will naturally be urgency to follow it up. There is also a plan to transition out of the highly successful Pierre Auger project in the very near future.

Given the importance of neutrino physics to the future program at Fermilab, one opportunity that might be worth considering is a program in neutrino astrophysics that complements and enhances the experimental neutrino program that will be hosted by Fermilab. In particular, ELBNF will have the capability to detect individual core collapse supernovae and to measure their integrated background.

In summary, the PAC is pleased to see the evolution of elements of an exciting strategic plan that has the flexibility to adapt to future scientific discoveries and expanded funding opportunities. It also notes, however, that a successful program at a National Laboratory must be based upon experimental leadership in major projects and this will likely require that hard choices will have to be made to strengthen fewer efforts at the expense of broad support of many programs. The PAC looks forward to a more detailed activity plan for particle astrophysics at Fermilab that addresses the points made here. This more detailed plan should address the need for a Fermilab flagship project once DES is successfully completed. It should also provide more detailed information on the technical and human resources to be brought to bear, and include information on planned postdoc and possible student deployment across the planned activities, especially for new initiatives.

Theory

In the light of the evolution of the experimental program at Fermilab we recommend that the Fermilab Theory Group present to the next PAC its plan and strategy to invest its resources in relevant scientific areas including proton decay, neutrino oscillations, neutrino astrophysics, dark matter, dark energy, and microwave background studies.