Fermilab Physics Advisory Committee Report
14-16 January, 2020

Executive Summary:

The Physics Advisory Committee met on January 14-16, 2020 at Fermilab as the laboratory continues its central role in executing key elements of the 2014 Particle Physics Project Prioritization Panel's (P5) "Building for Discovery", the strategic plan for US particle physics. The Committee received detailed updates on some of these elements, such as LBNF/DUNE, the Short Baseline Neutrino (SBN) program, and the CMS. Also discussed were recent developments both domestic, such as the new DOE initiatives in quantum information systems (QIS), and abroad, with the advancement of the Hyper-Kamiokande experiment and continued discussions on the International Linear Collider (ILC). The Laboratory's preparations for the upcoming US community planning process (Snowmass 2021) were also discussed.

At the meeting the PAC heard presentations which focussed on the outcome of recommendations made at previous meetings ("recommendations reports") and more general reports responding to both the charge and past recommendations ("full status reports").

The Laboratory Director reported on the status of the muon program, where the g-2 experiment recently completed a successful run, resulting in integrated statistics equivalent to nearly five times the BNL experiment ("5 x BNL"). Several technical issues reported at the previous PAC meeting were mitigated in the FY2019 shutdown and the first results from the experiment using data taken in 2018 are expected soon. Beyond, the goal is to deliver a data set equivalent to 20 x BNL by the end of FY2022. Also reported was progress on the Mu2e project, which aims to complete construction in CY2022, followed by a run to establish the world's most sensitive test of charged lepton flavor violation by CY2024 before the extended shutdown for LBNF/DUNE. Ultimately, an improvement of sensitivity by a factor of ten thousand over current experiments is expected.

The Director also reported on a realignment of the detector R&D program towards picosecond timing and noble element detectors following the Basic Research Needs workshop. Status reports on PIP-II, the PIP-III definition committee, and LBNF/DUNE were also provided along with discussion on Fermilab's potential role in future colliders in response to developments in the European Strategy update, the ILC, and the recent Critical Decision 0 milestone for the electron-ion collider (EIC) at Brookhaven.

The committee heard a report on the status of Scientific Computing at the laboratory, which included progress on the reorganization of the advisory committees discussed at the previous meeting, continued challenges in supporting critical scientific computing tools and developments due to reduction in funding and personnel, and a new data preservation and open data approach. The committee views the upcoming first meeting of the FCRSG to be important in defining near term planning. Likewise, careful planning and prioritization of R&D efforts will be needed given the limited resources.

The QIS program at Fermilab has seen rapid growth, leveraging the application of core expertise such as superconducting radio frequency (SRF) cavities and industrial and university partnerships. A new organization structure is in place and FNAL is co-leading an application for a National Quantum Center. The committee also heard about the recently formed Artificial Intelligence/Machine Learning (AI/ML) project to improve communication and coordination in machine learning efforts across the laboratory.

FNAL is the anchor for the substantial US CMS effort. A short term rebalancing of resources to mitigate the shortfall of computing resources for the Tier 1 center discussed at the last PAC meeting was presented. The committee also heard updates on personnel, the LHC Physics Center (LPC), and the irradiation test facility program for the outer tracker.

The Committee heard reports from several aspects of the neutrino program. The first publications from the highly successful ProtoDUNE-SP run are in the final stages of preparations, reflecting substantial progress in understanding and calibrating the detector. Plans for a second run using production components of the far detection module are now in development. The ICARUS detector is now in an advanced stage of commissioning with the imminent start of cool down operations aimed at bringing the detector into operation in late spring, which illustrates the effectiveness of the growing collaboration and the joint SBN structures. ANNIE, which also operates in the Booster Neutrino Beam, has successfully achieved full Gd-doping and is operating five ps-resolution LAPPD photon detectors, placing the collaboration on the path towards achieving its primary physics goals of neutron production measurements. The SBN analysis working group presented oscillation sensitivities using three different fitting frameworks where the proposal-era assumptions on detector performance were uniformly incorporated through a common framework. Work continues on reconstruction, systematics, and detailed simulation.

The LBNC, which oversees the developments in DUNE, has reviewed and approved four volumes of a technical design report, and has monitored progress in the ProtoDUNE program (including the dual phase NP02 module), the near detector, and the recently formed Computing Consortium. The LBNC also favorably assessed the process of the Neutrino Cost Group, which provides oversight over the cost, schedule, and risks. A multi-institutional memorandum understanding has been submitted to the DOE for review and approval.

The Committee heard a report on Hyper-Kamiokande, a 190 kiloton water Cherenkov detector that will observe neutrinos produced from the upgraded neutrino beam at J-PARC. The experiment brings a program of neutrino oscillations, nucleon decay, and astrophysics which has important complementarity to the DUNE/LBNF program while also presenting serious competition for some of its flagship goals, such as the observation of CP violation in neutrino oscillations. The project has received initial funding and is starting its construction phase with the aim to start operations by 2027. These developments highlight and amplify the importance of maintaining, and where possible, accelerating, the schedule for DUNE/LBNF.

Since the last PAC meeting, the ILC International Working Group has had additional meetings, and submitted a report of potential cost and governance sharing models to the

Japanese funding agency, following feedback from the DOE and other non-Japanese agencies.
The Committee heard reports both on the national Snowmass exercise, which is in advanced planning phases, and preparations within Fermilab guided by the Scientific Advisory Committee. Several key topics, which may result in contributions to related white papers, have been identified.
In the Cosmic Frontier program, several important decisions, including the siting of the LSST data center and the selection of the lead laboratory for CMB-S4, are imminent. The new Cosmic Physics Center continues to ramp up. The Committee also evaluated Fermilab's role in DarkSide.
The Committee thanks the speakers for their clear and informative presentations. In addition to presentations specifically addressing the charge to the Committee, we are grateful for the additional presentation from Young Kee Kim ("Status of the Snowmass process").
We also express our appreciation to the FNAL Directorate and the Scientific Secretary for the effective organization of the meeting.

The Physics Advisory Committee:
Present: Elena Aprile, Ayana Arce, Alexander Friedland, Ines Gil-Botella, Francis Halzen, Pedro Machado, Kevin McFarland, Stefano Miscetti, Hugh Montgomery, Christoph Simon (remote), Hirohisa Tanaka

Regrets: Florencia Canelli, Alex Szalay

Scientific Secretary: Anadi Canepa

Directorate: Gregory Bock, Joseph Lykken, Nigel Lockyer, Hema Ramamoorthi, Luciano Ristori

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Status of the Scientific Computing Program at the laboratory (full status report)

We ask the committee to review the status of S&C R&D at the laboratory including plans for migrating HEP computing to high performance architecture and for support to current and future experiments' operations. The committee is also asked to review the status of the new committee structure and recommendations made at the July 2019 meeting.

Findings:
The Scientific Computing environment at Fermilab is complex. Approximately ten experiments and efforts of varying sizes are supported, some of which fund their own dedicated computing resources (e.g. like CMS), while others, like ANNIE, fully rely on resources made available by Fermilab. In addition, most Fermilab computing users, particularly from the experiments, have not yet been able to take advantage of new

computing architectures even when this would in principle be advantageous, and therefore have limited options to request resources at other DOE computing centers.
The SCD presentation to the PAC included responses to all of the recommendations from the previous PAC meeting. Since the last review, Fermilab's SCD has taken several steps to address some of the organizational challenges. The two Computing Advisory Boards have been implemented: the International Computing Advisory Committee (ICAC), which has met and provided recommendations to SCD, and the Fermilab Computing Resources Scrutiny Group (FCRSG), which will have its first meeting in March. The preparation for operation plans for DUNE, CMS, and Mu2e were highlighted. Using developments from the HEPCloud effort, an efficient approach was developed to use currently available resources at NERSC. Fermilab hosted several effective computing workshops, and is targeting the training of intermediate-level software developers by providing tutorials.
DOE has recently initiated the CCE (Center for Computational Excellence) that brings together HEP and ASCR researchers from across the DOE complex. Fermilab researchers are participating in the CCE, and Gutsche holds a key position to develop an approach to enable the development of portable parallel HEP software. At the same time, funding for the CompHEP project was heavily reduced, leading to a reduction of the SCD workforce by 10FTE.

Comments:
New committee structure (addressing Recommendation 1):
The two advisory committees represent a step towards better coordination and planning of the computing resources needs. It is very important that the information collected by the FCRSG is coherent and detailed enough to enable a more rigorous planning process for the computing effort; this must be assessed after the group's first meeting.

Support and resource planning for current and future experiments' operations (Recommendation 2):
As described in the ICAC report, the resource planning and scrutiny needs to account for the different needs and funding models for experiments across the three frontiers. The request for a detailed computing plan for DUNE for the next 10 years needs to be accompanied by adequate flexibility to take into account the long schedule.
The presentation of the two highlighted plans (DUNE and Mu2e) did not provide enough detail for the PAC to evaluate if they will be adequate to carry out the requested planning exercise.

Inter-collaboration Information Transfer and Continued Education and Workforce Development (Recommendation 3):
The workshops held by Fermilab in September were well-aligned with SCD's mission and planning for future challenges. We encourage the Laboratory to continue to host these events in the future.

Prioritize Software R&D Efforts (Recommendation 4):

The priorities seem to be constrained by the available funding rather than the actual needs of the program. For example, GEANT development would have a broad impact but nevertheless ran out of funding and the SCD seems to have no free energy to continue the effort.

Migration of HEP computing to HPC architectures (Recommendation 6):
The use of HPC resources to deliver cycles to HEP experiments is a very important opportunity. For example, for the US CMS Collaboration, given the rising requirements from the experiment and the limited availability of other resources, Fermilab must start efficiently using those resources. However, this opportunity comes with technical challenges that the members of the scientific computing groups have started to address. The HEPCloud effort to enable usage of currently available NERSC resources has been a successful step in that direction and it is a concern that the current funding of further R&D on HEPCloud is not secure. Fermilab researchers are well-integrated in the CCE that recently started. The CCE is a multi-organizational project, and its impact on computing models such as that of CMS relies on contributions from other institutions.
It is very important to carefully monitor the required contributions for I/O and storage to ensure timely delivery. Therefore, it is essential to closely monitor the progress.

Support from CompHEP:
The reduction in funding from CompHEP has led to several problems. For example, there is no support for further developments of GEANT or the HEPCloud approach. Resources for developing and maintaining tools essential for HEP research are crucial and a solution has to be found to provide these resources.

Open Data Approach:
Fermilab SCD is supportive of a more uniform approach to data preservation and open data access. The committee appreciates that a gradual implementation of the data-lifetime policy proposed by SCD would have a positive impact on its ability to manage resources as well as facilitating a future data preservation policy, but developing a uniform open data policy could have consequences well beyond the Fermilab SCD scope. SCD policy and infrastructure can foster and reinforce initiatives developed within experimental collaborations and in conversation with computing management groups at other laboratories, keeping in mind available resources..

Recommendations:
SCD should present a detailed report to the PAC on how it plans to satisfy the very diverse computing needs of the various experiments. This plan should present the currently available hardware for all experiments and projects, and the users' usage patterns (such as how often the resources are used by experiments who have not contributed hardware). This report should also have information about the current support model for the users and the hardware, and point out where SCD anticipates major challenges in the future and how these will be addressed.

Given the importance of the FCRSG in a well-structured planning process for scientific computing, there should be a very careful assessment of the information gathered from the experiments after the first meeting in March, so that any needed adjustments to the process can be made. The PAC requests a report about the process and its outcome well before the next PAC summer meeting.
The PAC requests that SCD prepare a ranked list of high priority software R&D projects (including "sustaining capabilities") in consultation with the HEP community, explaining both the impact on projected future resource challenges, and how these high-priority developments can be sustained over the long term in realistic funding scenarios.

Report on the QIS program at the laboratory (full status report)

We ask the committee to review the status of the QIS program at Fermilab and the progress made in proposing the laboratory as a national center a well as the synergy of the Fermilab's and universities' programs. The committee is also asked to review the status of the recommendations made at the July 2019 meeting.

Joe Lykken presented the status of QIS activities across the laboratory. We report on each part of the charge in turn.

1. The status of the QIS program at Fermilab:

Findings:
We learned that Fermilab is now engaged in 16 DOE-funded projects in QIS. The size of the quantum program at Fermilab is now comparable to its Cosmic Frontier program. Fermilab is thematically consolidating its quantum activities in communication with DOE, resulting in four emerging 'tasks' - QIS and HEP theory, Quantum networks and analysis, SRF-based quantum technology and sensing, Quantum sensing for dark matter. In terms of internal organization, the lab has created the Fermilab Quantum Institute and installed a new leadership team. We also learned about collaborations with major industrial partners, in particular Google and Rigetti. There are new hardware investments, including dilution fridges for the SRF program and a new lab for quantum sensing. The MAGIS-100 project is moving forward and growing thanks to funding from the Moore Foundation and DOE. The IEQNET project (which is funded by DOE ASCR) aims to develop a Chicago-area quantum network in collaboration with university partners. We also learned about a new DOE quantum internet initiative and a related workshop that is planned in February 2020.

Comments:
The number and diversity of quantum projects is impressive.

A strong program was built up rather quickly and forms the basis for enabling strong additional proposals such as the Quantum Center.
The consolidation of the quantum program seems reasonable and should be useful for attracting funding in a sustainable manner.
The new quantum organization seems rational and should be helpful.
The industrial partners are strong, there seems to be great potential for technology transfer going forward.
The hardware investments demonstrate commitment to this area.
The continued progress and development of the MAGIS-100 project is encouraging.
The IEQNET project seems promising and will be a good basis for the quantum internet efforts going forward.

2. The progress made in proposing the laboratory as a national center:

Findings:
We learned that the call for up to 5 DOE quantum centers has recently been released. Fermilab has been working to co-lead a proposal since last July.

Comment:
Through its ongoing activities and program, the laboratory is well-positioned to lead a quantum center through its expertise in SRF and partnerships.

3. The synergy of the Fermilab's and universities' programs:

Findings:
The lab works with excellent university partners successfully on many projects (e.g. MAGIS-100, FQNET, IEQNET) and is actively reaching out to many universities across the various QIS themes. Universities are essential partners because of their expertise and also because they provide access to graduate students.

4. The committee is also asked to review the status of the recommendations made at the July 2019 meeting:

Findings:
The committee is pleased to see the progress on the recommendations made at the previous meeting.
The first recommendation was to explore the application of SRF cavities to quantum networks. We learned that the lab is working on connecting two SRF cavities in separate dilution fridges via microwave photons, which is an important first step. We encourage the lab to also explore microwave-to-optical transduction, which is a logical next step in view of applications to longer-distance quantum networks.

The second recommendation was to continue pursuing the quantum-computing related theory efforts. This has now become 'task 1' of the quantum program.
The third recommendation was to pursue the cryogenic electronics efforts. We learned that the lab is in contact with major industry partners on this topic.

Recommendations:
While the lab has made a strong start at developing its quantum program leveraging relevant existing internal expertise, external partnerships, and postdoc funding, establishing a vigorous longer-term program will require further hiring of staff members at the associate scientist and scientist level that are quantum experts to lead parts of the program, in addition to the one such hire that has recently happened.
We encourage the lab to explore international collaborations for the quantum internet initiative.

Status of the AI/ML program at the laboratory (full status report)

We ask the committee to comment on the scope and organization of the AI/ML program at the laboratory in the context of the new DOE initiative.

Findings:
Nhan Tran presented the status of the AI Project, which was initiated several months ago to help coordinate the AI/ML efforts across the laboratory.
The AI Project office was established with seven members and an additional 13 liaisons for different areas in the lab will be appointed to help communication with the project office. Some of the liaison positions still have to be filled.
The effort is built around four areas: theory and new algorithms, operations and control systems, computing hardware and infrastructure, real-time AI at sensor/edge. Examples for each area were presented.

Comments:
The area of AI/ML is very complex and touches upon a lot of areas in high-energy physics. It is, therefore, a difficult task to develop a coherent program with priorities. Forming the AI Project is an excellent first step in this direction.
Fostering communication between different parts of the laboratory is very important and, in general, the identification of liaisons is a good idea. It was not clear how the different liaisons interact with each other and how efficiently they communicate to enhance the overall effort.
The committee encourages the lab to establish metrics for the deliverables of the AI Project, particularly in the field of common frameworks and tools. This might help in identifying synergies and streamlining the effort.
The project office has seven members (some with leadership positions in other areas of the Laboratory) and this group must work together to establish a focused program

despite other commitments, for example, to organize a focused response quickly when funding opportunities become available.
The committee looks forward to hearing about new developments in the future.

Report on the CMS Experiment (recommendations report)

We ask the committee to review the status of the experiment and the status of the recommendations made at the January and July 2019 meetings.

Findings:
Oliver Gutsche presented the status of the CMS in a report focusing on the implementation of previous PAC recommendations. Within CMS, the Fermilab group continues to play a leading role in core activities in the experiment: software and computing, LS2 activities, Phase 2 upgrades, and preparation for the coming Physics run.
The PAC commends the CMS Fermilab group for its sustained success in supporting CMS activities. The profile of the Fermilab group in CMS is highly visible with almost half of the members of the group engaged in managerial positions. The Laboratory's involvement in the physics analyses remains at a high level, both through leadership in developing innovative techniques and also through its operation of the LHC Physics Center (LPC), which is a seed for new analyses efforts.
The PAC recommendations from the previous meetings were all addressed:
two associate scientists were hired to contribute to the Phase 2 project and R&D and to the evolution of Software and Computing. Three new RA's are also planned for FY20.
A plan for the Tier 1 computing resources end-of-year replacement has been devised with the support of DOE and lab's management. This includes a rebalancing of funds from the upgrade project.
A similar rebalancing scheme has been devised to keep the LPC program at its current level. This will ensure operation of the LPC for the next three years at the current level.
The irradiation test area, needed to validate silicon sensors for the outer tracker, is now on track and planned to be used by April 2020.

Comments:
The PAC recognizes the effort of the Laboratory in supporting the needs of CMS with a set of new hirings. It also acknowledges that the total number of CMS dedicated FTEs has declined by 10% in the last couple of years, a level at which the CMS group is strained to meet its current level of commitments.
Continuing shortfalls in funding for replacement of Tier-1 computing hardware will inevitably have an effect on the Tier-1 reliability. A plan for short-term reallocation of funds was discussed with the committee, which is effectively a reprofiling, and as presented will not have a long-term impact on the operations or upgrade budget. The committee endorses this approach.

The LPC is recognized as a very successful program seeding new analysis/software and detector activities, and serving the CMS community at large by educating a new generation of scientists. DOE funding for the LPC was reduced in 2019, and absorbed mostly by reductions in the Distinguished Researcher (DR) program. The impact of further cuts may lead to the termination of the CMS Data Analysis School (DAS) and Hands-on Advanced Tutorial Sessions (HATS) held by the LPC.
The CMS Fermilab group is leading the effort of expanding HPC usage to complement conventional computing resources for data and MC processing. It is also clear that the usage of HPC cannot fulfill all the needs of an experiment like CMS: the need for platforms with higher I/O capabilities limits current usage, and the middleware framework is not yet ready for fully efficient use of next-generation HPC.

Recommendations:
The Committee recommends that CMS understand how much the usage of HPC can be increased under the assumption that no additional resources such as personnel to adapt the current software are allocated.

Report on the ProtoDune Experiment (recommendation report)

The committee is asked to review the status of the experiment including plans for Run 2, and the status of the recommendations made at the January 2019 meeting. The committee will also review a potential Fermilab's involvement in the Dual Phase LArTPC.

The committee heard a report from Flavio Cavanna on the status of ProtoDUNE running and analysis, and on the future plans for ProtoDUNE, focussing on the recommendations made at the previous PAC meeting.

Findings:
ProtoDUNE-SP has now been running for over 500 days, long enough to assess the stability of operations. Lessons learned will feed into the design of many systems for the DUNE far detectors, as envisaged when the ProtoDUNE program was conceived.
ProtoDUNE-SP analysis is well underway. We heard about progress in understanding space charge, the diffusion model, and the performance of the photon detection system (PDS). ProtoDUNE-SP has achieved a major milestone in completing its first publication documenting its results. That publication is now in internal review within the collaboration.
ProtoDUNE-SP commented on its plans for a Phase-II run with more production components, and with the opportunity to take more hadron testbeam.
Fermilab continues a minor involvement in ProtoDUNE-DP, with work on the more challenging HV requirements for this detector.

Comments:

The committee congratulates ProtoDUNE-SP on its continued progress in advancing the technical design, operation, and understanding of the DUNE detectors, which should be also beneficial to other experiments employing the LArTPC technology.
Analysis and publication of the ProtoDUNE-SP data should remain a high priority for the DUNE collaboration. For this to succeed, it will be important to keep personnel focused on analysis. Exploitation of this data will continue to benefit the entire LAr TPC community.
Xe doping has been shown in small tests to be effective in increasing the light yield. The results from the planned tests in the current ProtoDUNE-SP will be of interest to clarify the role of this technique in Phase II and beyond.

Recommendations:
The Committee requests that ProtoDUNE-SP articulates its priority physics analyses, and that the DUNE collaboration ensures that sufficient resources are in place to realize publication of these analyses.
The Committee asks that ProtoDUNE-SP clarify its technical and scientific goals for Phase II in a future presentation to the PAC.

Report on the ICARUS Experiment (full status report)

We ask the committee to review the status of the ICARUS experiment including the preparatory work towards the SBN operations.

The status of ICARUS, the far detector for the Short Baseline Neutrino (SBN) program, was presented by Claudio Montanari.

Findings and Comments:
The PAC acknowledges the impressive progress made by ICARUS both in its technical accomplishments and increasing the strength of the collaboration. In particular, we commend the collaboration for completing the complex cryogenics installation, with a projected startup of cool-down operations in February and the cryostat filled with liquid argon by the end of April.
Progress since the last PAC meeting was also presented at the level of readout electronics, power supplies, cables, calibration and optical fibers. Integration of DAQ, slow control, trigger system and data handling is progressing well. The collaboration's goal to complete detector commissioning by the start of beam time in the Fall is aggressive yet realistic, given the available personnel and technical resources.
The PAC appreciated the effort to establish several joint WGs within the SBN program including common data management, slow controls and safety coordination.
The PAC acknowledges the additional information provided by the ICARUS collaboration about the activities for the first commissioning phase, data taking plan and personnel support.

Recommendation:
If the presented schedule is maintained, ICARUS will be operating and acquiring neutrino data without the near detector for a while. The PAC would like to hear what are the science goals that the collaboration plans to accomplish with this data and to specify the related computing needs.

Report on the ANNIE Experiment (full status report)

We ask the committee to review the status of the ANNIE experiment.

Findings:
Mayly Sanchez presented the status of ANNIE and the progress toward its primary Phase II physics goal of measuring neutron multiplicity as a function of muon energy and transverse momentum. This measurement will provide input for validation of intranuclear cascade models in neutrino event generators. The detector has been fully loaded with gadolinium since December 2019. In addition to using traditional photomultipliers, the experiment will also serve as a testbed for Large Area Picosecond Photon Detectors (LAPPD). Five LAPPDs have been received and are presently under testing at Fermilab. Simulations were shown that indicate that timing information from LAPPDs would make it possible to significantly improve vertex and direction resolution. This study shows progress on the full set of detector simulations that will be required to meet the primary Phase II physics goal.
The collaboration reported on a number of additional physics and technical goals beyond the primary ANNIE Phase II physics goal. These future projects include characterization of the visible recoil in the water volume, addition of a water-based liquid scintillator target, and the addition of more LAPPDs to enhance reconstruction. This has the potential to significantly expand the physics output of the experiment, including pion production and neutral current studies.

Comments:
The committee commends the collaboration on their accomplishments in detector commissioning, operations, and calibrations. They are making significant progress towards their primary Phase II physics goal.
With regard to the extensions to the primary Phase II physics goal, we encourage the ANNIE collaboration to develop the physics case for these measurements, and detailed technical plans for carrying them out. The PAC looks forward to hearing a report on these plans at a future meeting.

Report on the SBN analysis working groups (full status report)

We ask the committee to assess the progress made by the analysis working groups towards an integrated SBN physics program. The committee will also review the status of the recommendations made at the January and July 2019 meeting.

Findings:

Daniele Gibin presented the status of the SBN analysis working group. The PAC commends the SBN analysis working group for maintaining a steady pace in developing joint reconstruction, simulation and analysis tools for the SBN oscillation studies. The oscillation fit procedure has been carried out with three different fitting frameworks, adapted from existing experiments: NOvA, MicroBooNE, and T2K. All fitters access, through a common code, the same MC and data event samples, with the same SBN event selection, physics and detector systematics.
The working group presented the first comparison between the sensitivity estimates obtained with the three fitters, using truth-level information and the proposal-era assumptions on the signal efficiencies, background rejection, and the neutrino interaction model and systematics. Overall, the results are found to be in good agreement with the estimated sensitivity in the proposal, and with each other. This applies both to the muon neutrino disappearance and electron neutrino appearance, thus meeting the first January 2019 PAC recommendation.
Minor residual differences are observed for the 90% exclusion regions between the outputs of the fitters. The origin of these differences is being investigated by the working group. The effect of using a recent version of GENIE with a large normalization for the meson exchange current channel has been investigated. A reassessment of the sensitivities using more realistic estimates of backgrounds and systematics, as noted in the January 2019 PAC report, is in progress.
In the meantime, improvement on the full simulation has been carried out with a detailed modeling of the response for TPC wires, photosensors and CRT detectors. Detector-specific and data-driven description of noise and space charge effects account for differences between the near and far detectors. Common reconstruction and event selection tools for TPC, PMTs and CRTs and the first demonstration of cosmic background rejection matching TPC and light information were shown. Electron neutrino event selection and tagging need further development.

Comments:
The PAC concurs that the upcoming commissioning of the far detector operation will be a turning point for the SBN analysis group. The availability of actual data will be a major boost to the efforts to improve the understanding of the detector performance and the experimental systematics.
The presentation indicates an active exchange of results and expertise between the SBN analysis working group and the MicroBooNE collaboration. The PAC encourages the SBN analysis working group to continue, and expand where possible, its

engagement with MicroBooNE, as well as protoDUNE for the development of realistic reconstruction.

Recommendations:
The PAC recommends that the SBN analysis group explicitly identify the known sources of systematic errors and the best available estimates for each of them. Plans on how these estimates will be improved with the availability of new data should also be discussed.
PAC looks forward to oscillation physics sensitivity results based on the full event simulations and reconstructions.

Report from LBNC

We ask the committee to comment on the LBNC activities.

The PAC received a comprehensive report on the activities of the LBNC from its chair, Hugh Montgomery. LBNC oversees the status and developments of the Deep Underground Neutrino Experiment (DUNE), an international collaboration that will operate at the Long Baseline Neutrino Facility.
After a long review phase concluded in November, the LNBC has recommended for the approval of the four completed DUNE TDR volumes concerning: the introduction to DUNE, the DUNE Physics, the DUNE Far Detector Single-Phase (SP) technology, and the DUNE Far Detector Technical coordination.
The LNBC carefully followed the operation and data analysis of the ProtoDune-SP detector at CERN whose progress continues to be impressive. In the meanwhile, the ProtoDune Double-Phase (DP) detector has also reached a major milestone by starting operations. For this reason, the LBNC December 2019 meeting focused attention to the ProtoDune-DP progress and on the technology and system R&D programs. Development of a plan for the anticipated four Far Detector modules was also discussed.
At the same LBNC meeting, the progress on the Near Detector were presented with specific implementations of the three primary components. A Near Detector Conceptual Design Report is under preparation and is expected to be completed for the middle of 2020.
The DUNE computing consortium is now established and will act as the experiment interface to the world of HEP computing while providing resources for the ProtoDune data handling and reconstruction.
The development of the resource responsibility matrix for the experiment is led by the DUNE Resource Coordinator and the DUNE Finance Board. A multi-institutional Memorandum of Understanding has been prepared and is currently in the hands of DOE.
The primary oversight and scrutiny of cost, schedule, and risk aspects are provided by the Neutrino Cost Group (NCG), chaired by Steve Nahn. At the request of the NCG, the

LBNC analyzed a presentation of the scrutiny process and judged it to be well-organized, rigorous and effective. The NCG process started with a detailed examination of the resource matrix for the Single Phase Far detector modules. This first step is planned to be concluded in April with a presentation to the DUNE RRB.

Report from the Hyper-K experiment

The committee is asked to comment on the scope and schedule of the Hyper-Kamiokande experiment in the context of LBNF/DUNE following a presentation on the status of Hyper-Kamiokande. The committee is also asked to comment on collaborative opportunities between the two efforts.

In a talk by Masato Shiozawa from the University of Tokyo, the PAC was informed that the Hyper-Kamiokande (Hyper-K) experiment has received its first funding in the Japanese Fiscal Year 2019. The experiment is a third-generation water Cherenkov detector, like Super-Kamiokande, with 8.5 times the volume and with 50 cm photomultipliers which have twice the photon efficiency of those used in the present detector. The stated goal is to complete the detector construction and take first data in 2027. In parallel, it is planned that the J-PARC beam delivered to the detector will be upgraded from 0.5 to 1.3 MW over the same time period.
Because some of the most fundamental measurements in neutrino physics are at stake, performing the challenging measurements with two experiments using different techniques and systematics is highly desirable, and in fact required. Answering the question whether neutrinos violate CP symmetry deserves a dual measurement and having simultaneous data from DUNE and Hyper-K would create the ideal circumstances for achieving progress on the most fundamental questions in neutrino physics. Moreover, since the two experiments operate in different energy ranges, with different oscillation baselines, the comparison of their results opens up sensitivity to new-physics effects beyond the minimal paradigm of three-flavor mass-induced oscillations.
Other strong synergies exist in the supernova neutrino burst programs, where Hyper-K's signal will be dominated by electron antineutrinos, while DUNE will be mostly sensitive to electron neutrinos, making the two measurements highly complementary. Likewise, on proton decay, DUNE will explore decay modes that are hard to identify in a Cherenkov experiment such as Hyper-K. High power targetry is needed for the megawatt-class neutrino beam lines providing the beams for both experiments. Finally, both experiments require improved understanding of the neutrino-nucleus cross section physics. Accordingly, a development of a common, robust interaction framework spanning from sub-GeV to multi-GeV neutrino energies could be another natural point of collaboration.
At the same time, it is clear that with the advent of Hyper-K the DUNE physics program now has a serious international competitor. While the timeline put forth by the Hyper-Kamiokande collaboration seems ambitious, it should be noted that, in the past, both the

Super-Kamiokande detector and the T2K beam started operation on schedule. Moreover, the Hyper-Kamiokande detector uses a well-established technology. Therefore, the PAC takes the proposed HyperK timeline very seriously. It is essential that DUNE construction schedule not suffer any delay. Any opportunities to accelerate the construction of LBNF/DUNE and the increase of beam power should be explored..

Report from the ILC project

The committee is asked to review how a major involvement of Fermilab in the ILC would fit into its plans following a presentation on the status of the ILC Committee.

Findings:
The PAC heard an informative report from Andrew Lankford on the activities of the International Working Group for the ILC, which has met twice since the summer PAC meeting. In September, the Working Group delivered a report to KEK in which it mapped out viable frameworks for the cost sharing, ILC Laboratory organization, and planning to address technical challenges. It is encouraging that these recommendations were developed with feedback from the DOE and international funding agencies and promptly transmitted to MEXT.

Comments:
If Japan decides to move forward with the ILC project, Fermilab is poised to lead the US efforts in ILC pre-Lab and Laboratory activities. Indeed, at Fermilab, cavities with gradients higher than ILC design of 31 MV/m have already been developed, and the Laboratory will demonstrate a cryomodule exceeding the ILC design on a short time scale, aligning well with the technical demands of the accelerator.

Report from SAC on Fermilab's preparation for the Snowmass Process (full status report)

The committee is asked to review Fermilab's plan for engagement in the Snowmass 2021 following a presentation from the DPF on its plans for the overall process.

Findings:
The SAC presented a detailed plan for the Fermilab Snowmass preparation activities. Many of the SAC Working Groups correspond to the Snowmass frontiers. The SAC has already identified many topics where they plan to contribute White Papers.

Comments:

The interaction between the SAC and the IPPM is very fruitful and helpful in facilitating the planning process. This fulfills the recommendation from the previous PAC review.
The PAC was impressed by the effort that has already been put into the planning process. As the flagship DOE HEP laboratory, Fermilab is the natural host for the DPF's pre-planning meeting and we strongly support this proposal.

Report on the Cosmic program at the laboratory (full status report)

We ask the committee to review the status and future perspectives of the Cosmic program at Fermilab and the progress made towards establishing the CPC.

A comprehensive update of the cosmic frontier program was presented by Josh Frieman.

Findings:
The current effort at Fermilab in DES is gradually moving over to LSST. Fermilab has submitted a proposal to take on a major task for LSST data processing (SLAC and BNL are the other two labs with proposals).
Fermilab has partnered with Argonne and UChicago to develop a proposal to lead CMB-S4 (Argonne would be the host lab with Fermilab and UChicago being supporting institutions). The proposal will be presented to DOE in February.
The Cosmic Physics Center had a soft launch with two workshops. A major aim is to enable joint analysis and cross-correlation of data from experiments such as DES and SPT-3G, LSST, and CMB-S4 to make the tightest cosmological constraints as well as to develop a consistent framework for combining multiple probes of dark matter (collider, direct, indirect, astro) to optimize the future dark matter detection program. Cosmic neutrinos will play an important role as well.
The connection of the Detector R&D program to the Cosmic Frontier Program was highlighted.
Fermilab's important role in SuperCDMS was highlighted. Areas of FNAL leadership include, cryogenics, warm electronics, calibration, and infrastructure and integration. Several issues in the copper "cold box" have resulted in a redesign with reduced payload, though the ability to deploy the initial configuration of detectors is maintained.
In addition to these efforts within the Cosmic Frontiers program, the laboratory is supporting at a very modest level the INFN-led Dark Side (DS) direct detection experiment based on a massive liquid argon dual-phase TPC. The support has been to-date in the form of a cryogenic engineer and a senior scientist, shared with the Proto-DUNE effort at CERN.

Comments:
The program is well-balanced with efforts in dark matter, dark energy, and CMB science. It takes good advantage of areas of particular strength at Fermilab.

We commend Fermilab on successfully concluding the DES observational campaign and delivering exciting science results. We look forward to hear about Y3 and final cosmological results in the future.

The PAC encourages Fermilab to continue strong participation in the discussions about a future southern spectroscopic survey in 2030+.

In the dark matter program, a comprehensive approach including direct, indirect, colliders, and astrophysical (surveys) probes of dark matter was highlighted. The PAC strongly agrees with, and supports, the idea of a program that encompasses all components. Such an approach is crucial if we aim to fully understand the nature of dark matter.

The opportunity to take on a larger role in LSST operations (in particular the data processing) is very exciting but at the same time will be a major new responsibility. It will be a large new task for Fermilab Computing and requires very careful planning. A major risk is given by the LSST timeline: LSST will be on sky in about two years and setting up the infrastructure for a fully functional and performing Data Processing Facility will be challenging.

Fermilab plays a very important role in SCDMS. The PAC was pleased with Fermilab's effort to help overcome some recent problems caused by the vendor bid exceeding the project's budget and schedule.

The Cosmic Physics Center has started up and is evolving. We very much support this effort and understand that the process has to be developed carefully. We hope that the CPC will be able to have a big impact in the future. The CPC would be an excellent hub to host analysis of diverse datasets. In particular, the opportunity to cross-correlate different datasets and carry out joint analysis of data from surveys such as LSST and CMB-S4 is very worthwhile. Similar efforts for dark matter experiments and cosmic neutrinos are planned and we strongly support these activities.

The program is supported by several resources (including LDRD and detector R&D). This is an excellent way to sustain the effort and also develop new ideas (e.g. detectors, dark matter and QIS).

Recently, INFN and the DS Collaboration have asked for a more significant involvement of Fermilab towards the realization of the DS-20K experiment, to include scientific participation and overall project coordination. While a stronger role in DS-20K is clearly beneficial in view of the synergy and complementarity of the LAr technology used in both DS-20k and DUNE, it is the unique scientific potential of DS20k for the dark matter frontier which should motivate the laboratory in this direction, revisiting its cosmic frontiers plan if necessary. DS-20K will be the only LAr based dark matter experiment worldwide capable of achieving similar or even superior sensitivity to massive WIMPs expected from the LXe based experiments under construction now (XENONnT and LZ), while providing independent and complementary information, extending to very low mass region pursued by the other technologies of the Cosmic Frontiers program, given the different background discrimination capabilities. The PAC in general supports that if Fermilab contributes to a project in an engineering role it should also have the opportunity to get involved at some level in the science of the project.

Recommendations:

If Fermilab is chosen to take on a new role in LSST Operations (leading the data processing), the PAC would like to request a report at the next PAC Meeting about the progress, in particular with regard to the planning for computing support.

The Committee requests an update on CMB-S4 and Fermilab's contributions during the next PAC meeting. Given that by that time, DOE will have made a decision about the Host Laboratory for CMB-S4, Fermilab's role should be more clear by then.

The PAC was impressed with the SENSEI results and would like to hear about the project in more detail during the next PAC meeting.