Fermilab Physics Advisory Committee Meeting
June 22-25, 2015
Comments and Recommendations

Introduction

The Physics Advisory Committee (PAC) met at the Chicago Gleacher Center to evaluate the Laboratory progress in developing a program that is aligned 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 the Laboratory Strategic planning process. The exciting plan that is emerging nicely encompasses the direction set out by community and aligns with the P5 recommendations. The plan is centered on developing a flagship neutrino science program, driving Large Hadron Collider science and future upgrades, revealing precision science, advancing accelerator science, exploring cosmic science, and building for science.

Fermilab is preparing to host the world neutrino community. The PAC is extremely impressed with the rapid progress made by the laboratory and the Department of Energy to develop a new approach to the management of a U.S. facility geared to hosting a large international effort. The Laboratory has made extraordinary progress in creating a new international collaboration (DUNE) to address the long-baseline science program at the Long-Baseline Neutrino Facility (LBNF). We look forward to timely progress in providing a hostel to make international collaborators more welcome.

The charge of this PAC meeting was broad. The most important discussions focused on the two major Fermilab neutrino initiatives: i) a new long-baseline experimental facility (LBNF) and experiment (DUNE), and (ii) an expanded short-baseline program that complements MicroBooNE with the addition of near and far detectors (SBND and ICARUS, respectively). The Committee was asked to comment on the status of these efforts and the progress recently made.

At this meeting the PAC considered the *CAPTAIN-MINERvA* (P-1061) proposal and the *Direct Search for Dark Photon & Dark Higgs Particles with the SeaQuest Spectrometer in Beam Dump Mode* (P-1067) Letter of Intent (LOI).

The PAC heard updates on the ongoing Fermilab neutrino program that consists of the laboratories flagship experiment (NOvA), two other NuMI experiments (MINOS+ and

MINERvA), and the new short baseline experiment (MicroBooNE). The committee was asked to consider the long-term future of MINERvA, including the proposed CAPTAIN-MINERvA extension to the experiment, and future antineutrino running.

Reports on two new muon experiments that will be added to the Fermilab program, g-2 and Mu2e, were presented. The PAC was asked to comment on progress towards realizing these experiments and achieving their scientific goals.

Presentations on other important aspects of the Fermilab program, including the status of the accelerator complex, the Fermilab Testbeam Facility (FTBF), CMS at the LHC and its upgrade(s) were given. The PAC was invited to comment on these activities.

The PAC heard an update on the Particle Astrophysics planning and was asked to comment on progress towards a more complete documented strategic plan for involvement of the laboratory in future particle astrophysics experiments.

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 Laboratory Strategic Planning

The PAC commends Fermilab on the development of a robust institutional strategic planning process. Indeed, now is a good time to be establishing such a process, while there are clear overall priorities for the national HEP program set out by the recent P5 report. The planning process described to the PAC is an excellent start in setting out such an institutional planning agenda with flow down from long-term priorities set out by P5 to long-term laboratory goals to year-by-year objectives. The inclusive nature of the initial planning process is also commendable for its engagement of the broader science community at Fermilab and beyond.

Fermilab management may want to consider how the laboratory line management will take ownership of executing and completing the near-term objectives embodied in the Lab Agenda. The Fermilab strategic plan necessarily ties closely to the priorities set out by the OHEP and the fiscal constraints exercised by funding delivery from DOE.

In taking on a larger role of advising Fermilab management on overall strategic issues, instead of individual program proposals, the PAC would like to have a more in depth understanding of strategies behind the major program themes that have been laid out and the process by which implementation priorities will be set in the annual lab agenda.

Fermilab management may want to consider informing and discussing with the PAC the planning and outcomes from major DOE institutional or programmatic reviews.

As part of the lab strategy, the connection and relation to the rest of the US and international community should be fostered and more explicitly included. Initiatives such as the very successful LPC and the test beam facility play a key role in the lab support to the rest of the community. Similar initiatives to foster the national and international community in other areas, such as neutrino physics, should be explored.

PAC strongly supports the current lab strategy of having a flagship neutrino program together with a diverse portfolio that includes several other experiments in the intensity, energy, and cosmology frontiers. Such a broad program should still be coherent (from a technological and/or physics point of view) while at the same time leaving some space for creativity (e.g. new projects and initiatives with strong potential for the future, and blue sky R&D).

LDRD funding is a way to support innovative new efforts and a means of providing young scientists with the opportunity to develop new and potentially groundbreaking ideas. The PAC would like to hear more about how this program is implemented and managed.

The PAC welcomes the opportunity to provide input on strategic questions for the laboratory in a broad discussion with the Director and Deputy Director, but suggests that such discussions occur later in the meeting when the PAC will have the full programmatic context.

The Neutrino Program

Future Long-Baseline Neutrino Program (LBN)

The committee was asked to make the following evaluations of the long-baseline neutrino program:

i. *We ask the PAC to comment on the current situation and on the progress being made by the collaboration to form Working Groups to address the open R&D questions.*

ii. *Is the documented science program for DUNE clear and compelling?*

iii. *Does the collaboration have a clear strategy, and associated plans, to explore how to achieve the required small systematic errors?*

iv. *Are there additional actions the laboratory should take to strengthen the internationalization of the LBNF/DUNE program?*

LBNF/DUNE

The PAC commends the laboratory on the extraordinary progress made since its last meeting in creating a new international collaboration (DUNE) to address the long-baseline science program at the Long-Baseline Neutrino Facility (LBNF). In the space of 3 months, collaboration leadership has been put in place, key strategic decisions have been taken, an exciting neutrino CP violation program that well exceeds the requirements of the P5 report and a complete and comprehensive CDR have been developed, and a credible cost and schedule laid out. The recently completed Director's Review, while providing additional important advice in preparation for the CD-1R Review, also was a strong endorsement of the progress made by DUNE and LBNF. Key near-term milestones coming up are CD-1R in July and CD-3a (LBNF). However, there is still a lot of work to do, including, in the near term, filling out the key management positions in the LBNF and DUNE projects, establishing the working groups and coordinators for DUNE, and launching the three task force groups to look at the Far Detector (FD) development plan, Near Detector (ND) requirements and concept development, and beamline optimization.

The PAC would also like to highlight several critical issues:

- A full capability for end-to-end simulation and reconstruction of events, extending from neutrino flux to final statistical analysis, is urgently needed. Such an effort would go well beyond the existing GLoBES performance estimates in terms of reliability and detailed performance assessment. There has been a long-standing need for such a tool for the LAr technology and it is essential for a robust understanding of physics reach and design optimization of both the FD and ND. Since SBN LAr detectors are also developing fully automated event reconstruction, close connections should be maintained to advance the state-of-the-art as quickly as possible driven by TPC data.
- Near detector (or ND complex) design and impact. The PAC encourages the broad engagement of the DUNE collaboration in the process of understanding the requirements and conceptual design of the ND. In the next 12-18 months, the ND task force should also develop a strategy for incorporating additional knowledge on neutrino events, their reconstruction, and relevant neutrino cross sections from LAr and neutrino cross section efforts coming online. In this regard, more work should be done to evaluate the importance and impact on systematic error improvements by planned programs such as CAPTAIN-MINERvA, even though initially the CP violation program will be statistics limited.
- The PAC sees a potential issue with growing the number of active people in the collaboration. The efforts to establish Task Forces and WGs are very important as a way of engaging collaboration members. The collaboration must continue to

grow, either naturally as the project gains visibility and momentum, or through dedicated efforts to target specific groups/nations.

DUNE should consider designating an R&D coordinator or coordination committee to integrate the many relevant R&D efforts that are not formally part of the DUNE project.

Fermilab may want to consider creating a forum for exchanging ideas and for aiding progress on LAr event reconstruction. The issue is not just providing a common software platform (this is clearly critical) but also facilitating a forum where scientists (especially young ones) can discuss common issues. Fermilab may want to encourage the major LAr collaborations to consider mechanisms for effective and efficient parallel development and transfer of knowledge.

The PAC is very impressed with the laboratory's efforts to internationalize the long-baseline neutrino program. We encourage the ongoing engagement of the full international neutrino community in exploring the rich physics enabled by LBNF through periodic workshops and planning meetings.

LBNC

The PAC congratulates the LBNC for the key role it has very successfully played since its inception in monitoring and overseeing the activities of LBNF/DUNE and advising the Fermilab Director on the development of this key scientific program.

The PAC further recommends that the LBNC appoints a SBN subcommittee which oversees and advises the Laboratory on coordination among the MicroBooNE, SBND and ICARUS collaborations and other LAr detectors at Fermilab and at CERN both from the technical and physics points of view. The same subcommittee should also monitor the knowledge exchange and coordination of efforts between the SBN and LBN programs.

The PAC would like to see regular communication from the LBNC Chair in order to be more continuously informed of progress with the flagship LBNF/DUNE program. The list of focus areas laid out for the LBNC over the next 6 months appears to be complete and appropriate.

Future Short-Baseline Neutrino Program (SBN)

The committee was asked to make the following evaluations of the short-baseline neutrino program:

i. *We ask the PAC to comment on the current situation and on the progress being made on MicroBooNE, SBND, and ICARUS.*

ii. *Is the path to Stage 2 approval for SBND and ICARUS (and extended MicroBooNE running) clear and appropriate?*

iii. Is there an adequate plan for the three collaborations to develop a strategy of cross calibrations that will lead to an understanding of the relative acceptances at the required level?

The committee was given three presentations on short-baseline neutrino efforts: a dedicated progress report on the MicroBooNE experiment; an overview of the progress on the coordinated three-detector program involving SBND, MicroBooNE, and ICARUS; and a description of the upgrades being made to the Booster Neutrino Beam.

The committee congratulates the MicroBooNE collaboration on achieving CD-4 and the start of liquid argon filling. With a complete fill only weeks away, it is clearly a very exciting time. The collaboration handled well the unexpected development of noisy channels, and it is fortunate that this will not pose a significant risk to the physics program. The collaboration has an excellent plan for moving forward on commissioning and calibrating the detector.

The committee was also pleased to see the progress on event reconstruction, and appreciates the enormous effort from the collaboration in tackling this extremely complex problem as a vanguard for the overall LAr-TPC program at the Laboratory. Nevertheless, it is clear that with data only months away, there is much work to be done to get reconstruction to the point where significant data analysis can begin. The committee believes that it is critical to quickly demonstrate the promised capabilities of the LArTPC technology. We appreciate the amenability of the MicroBooNE collaboration towards accepting new collaborators in this effort. The Committee recommends that the Laboratory closely monitor progress, and identify and provide relevant resources and expertise towards catalyzing this effort.

The committee would like to see, at the next PAC meeting, a sensitivity study that includes as much existing reconstruction as is available, and includes a demonstration of the required rejection of backgrounds (such as those from π^0s). A comparison of key metrics in efficiency, particle identification, resolutions, background suppression, etc. relative to those assumed in the initial sensitivity estimates would be helpful in assessing the overall status and where additional effort is needed.

The committee also noted that, while the other LArTPC experiments in the BNB are designing external cosmic veto/trackers, MicroBooNE does not have one. The rejection of cosmics may not work as well for low energy neutrino events. There is therefore a risk to the physics program, and the collaboration should carefully evaluate whether a design of such a system is needed.

The SBN program continues as a critical part of the development of the LArTPC program leading up to DUNE, as well as addressing the outstanding anomalous results seen by LSND and MiniBooNE. It is very well aligned with the program outlined by P5.

Significant progress towards finalizing the design of the SBND and ICARUS buildings has been made. There has also been impressive technical progress, from the preparations for the arrival of ICARUS to the design work on the SBND TPC, photon, and counter systems. The support from DOE, NSF, CERN, INFN, STFC, and SNSF has been critical to the rapid progress.

There appears, however, to have been very little progress on coordinating the plans for analysis across all three of the experiments. While this process is understandably sociologically complex, it is nevertheless critical to the success of the SBN program. Questions that range from data formats to common flux generators to blind analysis schemes will need to be answered, and quickly.

The SBN program has laid out a review path toward achieving Stage 2 approval. The Committee feels that, as part of that approval, a plan for coordinating the analysis programs across all three experiments will be needed.

There is an additional concern that, particularly for MicroBooNE and SBND, the overlap of the collaboration membership is very high, and higher still with membership in DUNE. As MicroBooNE begins the necessary focus on data analysis, there is the danger that progress towards a unified analysis effort across the three collaborations and necessary design work for SBND will lag.

Additionally, the schedule for SBN as a whole, and SBND in particular, is very aggressive. With the TPC design only being finalized now, there is very little flexibility if the program as a whole is going to be taking physics data in 2018. The Committee is concerned that maintaining this schedule, as SBND collaborators also participate in MicroBooNE and DUNE, will be a significant challenge.

The presented upgrade paths for BNB are a promising way of extending the reach of the SBN program. While the costs may be significant, the benefits (and potential savings) of realizing the SBN goals earlier should be considered. Both MicroBooNE and ICARUS are likely to be statistically limited, and therefore a gain in neutrino flux of 50-70% would be an important improvement. The committee supports the continued study of this upgrade in coordination with the experimental collaborations.

MINOS+

The PAC notes the significant progress made by MINOS+ in standard long-baseline oscillation physics, but in particular in searches for non-standard neutrino physics, such as sterile neutrinos, extra dimensions, and non-standard interactions, which are very interesting and add significantly to the knowledge we have of neutrinos.

With the additional data anticipated through 2016, MINOS+ will be able to achieve its scientific goals and play an important role in building a more precise picture of neutrino properties and testing the standard 3-neutrino mixing paradigm.

In view of the upcoming end of the project, the PAC encourages collaboration members to join other running and future neutrino experiments. This is particularly important given their valuable expertise in data analysis, both for standard and even more importantly non-standard neutrino physics.

NOvA

The PAC congratulates Fermilab, the NOvA project, and the NOvA FPD for the Secretary of Energy's Award of Excellence upon completion of the NOvA project. The experiment is now fully operational and collecting high-quality long-baseline neutrino data with about 95% uptime. Further operational improvements are being implemented.

Analyses on ν_μ disappearance and ν_e appearance are underway and first results are anticipated in the coming months. The PAC commends the blind analysis approach being taken.

There are some questions about when NOvA plans to change to antineutrino running and how this fits the MINERvA plans. The PAC is interested in hearing more about a coordinated plan for delivery to NOvA, MINERvA, and the Muon Campus at its next meeting.

The PAC notes the decision path presented by the collaboration, which projects a decision point to switch to antineutrinos by the summer shutdown in 2016. The PAC believes that the precision for comparison with T2K is probably not consistent with seeing a statistically significant deviation at the 20% level.

MINERvA

The Committee congratulates the MINERvA collaboration on its growing portfolio of important neutrino interaction measurements that are advancing the field of neutrino-nucleus interactions. These measurements will continue to play a critical role for current and upcoming neutrino oscillation experiments in developing their neutrino interaction models and constraining their systematic uncertainties.

The Committee was asked to revisit the MINERvA request for antineutrino running with $12x10^{20}$ protons-on-target at NuMI, and to address the following questions in light of the realignment of the Fermilab program to the P5 recommendations.

i. Is the science case for antineutrino running interesting and/or compelling?

The committee believes that a high statistics sample of antineutrino data from MINERvA is necessary for the experiment to complete its scientific goals, which (as noted above) are an essential ingredient for further global progress in understanding neutrino-nucleus interactions. We note that in contrast to other experiments (T2K, the BNB-based experiments, etc.), MINERvA measurements will be performed in a more optimal energy range for DUNE. Measurements on a variety of targets are also important for developing a more fundamental understanding and modeling of nuclear effects.

ii. Given the uncertainties on the beginning and duration of NuMI antineutrino running, what is the minimum amount of antineutrino data (POT) needed for the science case to be strong?

The statistics are lowest for the carbon target, where a few thousand events are expected for $6x10^{20}$ POT, allowing a statistical uncertainty of several percent in each x_B bin. While it is difficult to specify a precise threshold, the committee believes that it would be important for MINERvA to acquire at least this level of antineutrino exposure. We note the importance of the carbon data in spanning a sufficient range of atomic number and providing a measurement with a target lighter than argon to allow a reliable interpolation of nuclear effects.

The MINERvA Collaboration noted their flexibility with regard to the running sequence. In particular, it is not necessary for the antineutrino exposure to be taken at once, and it can be interspersed with additional neutrino running in accordance with the demands from other experiments in the NuMI program. With significantly more antineutrino mode running planned for NOvA in any case, we hope that the targeted goal ($12x10^{20}$ POT) can eventually be achieved, even if an initial exposure is less.

iii. What is needed to make MINERvA antineutrino running successful?

With the MINERvA collaboration now producing a steady stream of measurements with mature analysis tools, it will be important to converge soon on when NuMI antineutrino running can be expected so that the collaboration can plan accordingly. *The Committee recommends that the Laboratory consult with the relevant experiments towards identifying an approximate date at which NuMI antineutrino running can start.*

In addition, the committee is concerned about the strength of the MINERvA collaboration given the analyses goals and the operational tasks ahead of them. *We recommend that the collaboration makes a concerted effort in recruiting more university collaborators from the US and abroad.*

The CAPTAIN-MINERvA Proposal

The committee thanks the CAPTAIN-MINERvA collaboration for their detailed and extensive proposal, which lays out a very strong science case for the experiment. The experiment would be capable of making critical measurements of neutrino cross-sections on argon, taking advantage of the existing MINERvA detector and (at least as importantly) the expertise on measuring neutrino cross-sections of the MINERvA collaboration. By making measurements of argon cross-sections in the same apparatus as used for measuring in other nuclei, there will be a useful cancellation of systematics which will be helpful for comparing the results directly to theory. In addition, the creation of a dataset of neutrino events in a LArTPC with additional tracking information from another detector may be useful in developing LArTPC reconstruction. We encourage CAPTAIN-MINERvA collaborators to work with the other LArTPC collaborations on this topic.

In response to the specific questions asked concerning this proposal:

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

We find the science case for CAPTAIN-MINERvA to be compelling, in that it will measure inputs critical to the laboratory's flagship experiment LBNF/DUNE.

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

The limited acceptance and containment for neutrino events in the CAPTAIN-MINERvA combination is not ideal, and would be expected to be better in an experiment designed from first principles to make these measurements. However, given the great cost-effectiveness and attractive schedule resulting from combining existing assets, we think these are acceptable drawbacks and the proposed experiment is therefore very appropriate and capable of reaching its physics goals.

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?

There is no real competition for these measurements. Of course, information on cross-sections will come from the detectors in the SBL program, but as these lack a magnetic field they do not provide sign selection. The proposed CAPTAIN-MINERvA experiment would also provide a better measurement of particle momenta. In the long run the LBNF near detectors will make such measurements, but since their detailed capabilities are currently unknown, the opportunity of making these measurements now should not be missed.

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

The proposal lays out a detailed set of technical requirements needed for the experiment, however we have more recommendations laid out below.

Based on the importance of these measurements and the advantages of making them using existing collaborations/equipment, *we therefore recommend Stage 1 approval for the CAPTAIN-MINERvA experiment. We further recommend, given the need to complete these measurements while the MINERvA collaboration is still extent and in time to impact preparations for the DUNE experiment, that the CAPTAIN-MINERvA program be considered more urgent than the CAPTAIN BNB program and therefore be executed first. We recommend the following before CAPTAIN-MINERvA is considered ready for Stage 2 approval:*

1. *There is data from mini-CAPTAIN which demonstrates that CAPTAIN will have the capability to perform the required measurements.*
2. *All the technical and resource questions, in particular the ones concerning the availability and suitability of the cryogenics support for CAPTAIN, should be satisfactorily answered.*
3. *The collaboration should demonstrate how they would perform the automated reconstruction of events from the combined detectors.*
4. *An evaluation of how the limited acceptance and containment of events in CAPTAIN-MINERvA impact the usefulness of any results to DUNE should have been made.*
5. *The CAPTAIN-MINERvA Collaboration should be sufficiently strong to be able to operate the detectors and deliver the full physics program.*

The Muon Program

g-2

The PAC heard a status report from the g-2 experiment aiming at measuring the muon anomalous magnetic dipole moment with a precision of < 140 ppb with an increase by a factor of 21 in statistics and a factor of 2.4 reduction of total systematic uncertainty from the previous E821 experiment at BNL.

Since its last report to the PAC, there has been impressive technical progress in the preparation of the experiment. The major milestone of reassembling the ring in its new building and the cool down and powering of the magnet for the first time has now been accomplished. The PAC congratulates the team for this accomplishment. Efforts are ongoing to reduce the precession systematic errors, to reach higher magnetic field

uniformity, and to improve on the monitoring and calibration of the various elements. They have recently produced a TDR and appear to be on schedule to begin taking data in 2017.

The interest in the apparent discrepancy between the measured and computed anomalous magnetic dipole moment remains very high. From the theoretical side, significant work is required to reduce the uncertainty, in particular from the light-by-light scattering diagrams and from the hadronic contribution, which benefit from the improved e^+e^- measurements at low energies. The Fermilab lattice group might be employed to strengthen these efforts.

Mu2e

The PAC heard a presentation by the Mu2e Collaboration on the recent progress of the experiment. The Mu2e experiment studies charged lepton flavor violation by searching for muon conversion to an electron in the presence of a nucleus. The goal is to reach a single-event sensitivity to branching fractions of $2x10^{-17}$, which represents an improvement of four orders of magnitude over the present limit. Mu2e is a clean search for physics beyond the Standard Model that is sensitive to mass scales of several thousand TeV.

The PAC is impressed with the significant progress of the experiment, which has recently been granted CD-2/3b approval. Tracker, calorimeter, and extinction monitoring technologies have been chosen. Sophisticated simulation tools have been implemented to study backgrounds, detector resolutions, and beamline design in detail. Prototypes of the straw tubes, solenoid, and target station have been developed. Issues with heat and radiation shields, as well as impacts of neutrons, have been studied. The fabrication and quality assurance of the transport solenoids are now on the critical path.

The COMET experiment at J-PARC is in direct competition with Mu2e, so it is important to keep the experiment on schedule. The PAC commends the Collaboration on the progress, and encourages the Laboratory to continue its strong support for the experiment.

Accelerator Status and Plans

The PAC is delighted to see the excellent progress being made in ramping up beam power for NOvA, with an ultimate goal of 700 kW. Recently, slip stacking (2+6 batches) has been achieved in the Recycler, bringing beam power to 450 kW. After the summer shutdown, the goals are to increase intensity with 6+6 batches while systematically reducing recycler beam losses, allowing an approximate doubling of the POT to NuMI in FY2016.

The Proton Improvement Plan requires doubling the proton source throughput and therefore halving the booster losses. Good progress is being made with additional work scheduled in the upcoming shutdown

Three possible pulse schemes have been developed to deliver protons to the Muon Campus as well as NuMI. These offer tradeoffs in terms of delivery to NOvA, g-2 and Mu2e and all three schemes can be interleaved to allow further flexibility.

The Laboratory should continue to strongly support development on the neutrino beam capability as an essential underpinning to the core program. As noted under the NOvA program, the PAC is interested in hearing more about a coordinated plan for delivery to NOvA, MINERvA, and the Muon Campus at its next meeting.

P-1067: Letter of Intent for a Direct Search for Dark Photon and Dark Higgs Particles with the SeaQuest Spectrometer in Beam Dump

The PAC recognizes the exciting opportunity brought by P1067 to search directly for a dark photon and dark Higgs in high-energy proton- nucleus collisions using existing SeaQuest Spectrometer (E906/E1039) in beam dump mode. P1067 could see or exclude the existence of dark photons and dark Higgs over a wide region of phase space in a short time scale and with a minimal cost. In addition, the impact on data collection during the upcoming E1039 experiment is expected to be small. To achieve these goals the collaboration must develop a new displaced vertex-trigger. Initial studies indicate that the installation of two planes of finely-segmented scintillating-strip tracking detectors in the SeaQuest dimuon spectrometer would fulfill the requirements for both triggering on displaced dimuon vertices and rejecting low- mass combinatorial dimuon background.

The collaboration has asked the PAC to:

- Approve the inclusion of new elements necessary to make a dark sector trigger. The necessary equipment will be constructed and supplied by the collaboration.
- Approve the parasitic collection of this data during E1039. In the unlikely situation that parasitic data collection during E1039 is not possible, approve a short, up to one month dedicated data collection period.

The PAC believes that P-1067 offers exciting physics prospects and recommends the Laboratory to grant these modest requests.

The PAC advises the collaboration to perform more detailed studies on possible background sources and encourages the collaboration to evaluate the full physics program that a run in beam dump mode could access. A proposal for a dedicated experiment, or a parasitic experiment with electron and hadron calorimeters, should be based on the results obtained with this first phase.

The FNAL Testbeam program

The PAC commends the Laboratory for the success of the Fermilab Testbeam Facility (FTBF) which began operation in 2005. The facility has two beam-lines: MTEST and MCENTER for short- and long-term users, respectively. It is constantly evolving to provide stronger support and optimize its operation.

The growth in the number of experiments, collaborators, institutions, and countries served by the FTBF has been simply spectacular. The FTBF leadership and supporting team are to be commended. In FY14, partially due to the CERN shutdown, FTFB served 19 experiments with 321 collaborators from 84 institutions in 20 countries.

The facility does not only provide a test bed for detector development but also a unique training facility for students and postdocs. The PAC heard a report from a committee charged to review the FTFB. *We agree with the finding of this committee and we recommend the Laboratory to take steps to implement a system of electronic signatures and to improve and streamline the application process*. We also encourage the Laboratory to continue improving their understanding of FTFB user base and their needs.

Particle Astrophysics Plan

The committee was asked to make the following evaluations of the Particle Astrophysics Plan:

i) Is the motivation for the laboratories involvement clear and compelling? Are the associated strategic objectives for the laboratory clear?

ii) Does the documented plan contain sufficient detail to make clear how the objectives can be achieved? Is the scope of the proposed activity appropriate? Is enough effort foreseen in the plan?

iii) Finally, does the overall plan have a scope, coherence, and impact that is appropriate for Fermilab?

The PAC heard a presentation describing updates in the strategic planning process for the Particle Astrophysics Program at Fermilab. As was true of the previous version (January, 2015), the PAC notes that the plan continues to be well aligned with the recommendations of the P5 committee and describes in general terms a broad set of activities that aim to push the program forward over the next decade. The program divides more or less neatly across the dark matter and cosmological survey efforts. One major change from the January presentation was the shift in priority in CMB back to a program with a very similar balance between surveys and dark matter to what is the case currently. This change followed along the lines of the recommendation made by the PAC in January.

The documented plan did not contain sufficient details to enable us to assess the path towards achieving the desired objectives and the level of the eventual impact. To better

understand the technical objectives, motivations, and the underlying strategic objectives, the PAC would suggest a presentation of the full program in a matrix format. For each project, we would like to see the following listed: 1) unique technical contributions, 2) Fermilab science roles, and 3) timelines for staff and postdoc efforts in both areas. This will help clarify the technical capability and science drivers for each project, and allow cross-cutting synergies to be properly presented and assessed. The management structure and the flow of funding into the Cosmic Frontier effort at Fermilab are not clear to the PAC. It would help us greatly if this information was presented in the future.

The current plan lists a number of projects, with roughly 3-5 FTEs assigned to each. (There are some much smaller R&D efforts that we do not consider here.) While this minimal number of FTE assignment does assure a useful presence in each project, the prioritization of the various activities is difficult to ascertain. It would be very useful for the PAC to have this prioritization information.

In the last report, the PAC noted Fermilab's impressive past record in the area of direct dark matter detection. We had suggested, however, that the Lab consider "making larger technical contributions towards fewer experiments." Our understanding is that this process is currently underway; the PAC hopes to be updated on this process as it unfolds.

In the January report, the PAC had noted the pioneering work done at Fermilab in making modern cosmological surveys a reality. We are happy to see that the current version of the plan does involve a serious level of effort for both DESI and LSST. It would be useful to understand the scientific leadership role envisaged for Fermilab staff, since details regarding this were not provided. The PAC notes that the DESI and LSST science working groups are already significantly active and Fermilab staff should identify opportunities for action as soon as is practical.

DES

The PAC heard a comprehensive presentation on the current status of the Dark Energy Survey, which now has more than 400 international members. Fermilab, the host laboratory for DES, is to be congratulated on the successful deployment and continued operation of DECam, which has now completed three seasons of data-taking (including the first year of "Science Verification" data). DECam is also the basis for the Dark Energy Camera Legacy Survey (DECaLS), a public optical imaging survey that also serves to provide targets for the Dark Energy Spectroscopic Instrument (DESI). DES has operated at a very high fraction of up-time, has observed 90% of the original Year 1+Year 2 goals, and image quality is meeting the nominal survey requirement of 0.9 arc-sec for weak lensing. The supernova survey is gathering Type Ia supernovae at roughly the expected rate.

Science results from the early DES dataset are now appearing, including a ~150 sq. degree weak lensing mass map and the discovery of nine satellite dwarf galaxies (found by a team at the University of Cambridge and by DES). A number of other results from DES (including cross-correlations with cosmic microwave background measurements) bode well for extracting precision cosmology constraints in the near future. Data from DES is made publicly available following a rolling release schedule, one year after initial imaging. Year 1 public data is already available to the community. The PAC noted that it is important to maintain data processing schedules for the DES Collaboration, as the survey science analysis needs to keep pace with the public data releases. The PAC would like to be kept informed of progress as DES continues along its exciting path of scientific discovery.

USCMS Phase 2 and Fermilab CMS Run2 Program

The committee was asked to make the following evaluations of CMS:
i*) We ask the PAC to comment on the current situation and on the progress being made with the Phase-2 upgrades.*

ii) We also ask the PAC to consider the Fermilab groups physics and analysis activities and comment on the scope and strength of these activities given the size of the group.

The PAC commends the Laboratory for the excellent support it is providing to USCMS. The collaboration is ready for the LHC Run 2 at 13 TeV and it is successfully carrying out the Phase 1 upgrade. The Laboratory has also put in place a strong management structure to guide USCMS through the challenging Phase 2 upgrade for the HL-LHC. This is required in view of the large scope and because Phase 2 preparation must proceed in parallel with the 13 TeV LHC Run 2 and the commitments for Phase 1. Vivian O'Dell, the U.S. Phase 2 Upgrade Project Leader, has organized several upgrade workshops to focus the USCMS community strongly behind the Phase 2 upgrades.

The PAC heard presentations on a) the status and work towards the CMS Phase-2 Upgrade project and b) current and future science yield from the CMS Fermilab group.

Fermilab is responsible for the entire USCMS Phase 2 management. SIDET is a major silicon facility that will be utilized in the construction of the strip silicon tracker and the High Granularity Calorimeter (HGC) production and integration. The Committee notes that between ATLAS and CMS, the LHC Phase 2 upgrades will require a dominant part of the silicon market, and vendors will need to be identified to ensure the project's success. The Committee looks forward to hearing the explicit Fermilab Phase 2 program (besides the USCMS one) at the next PAC meeting.

Fermilab has a large effort in CMS with 55 authors including 16 postdocs, 1 Lederman Fellow, and 2 Wilson Fellows, one of whom received a DOE Early Career award. It hosts

the LHC Physics Center (LPC) which provides a broad range of CMS expertise at one site, and is recognized to be of great importance for USCMS and the full CMS collaboration. The PAC is impressed with the impact of the LPC, which it believes could serve as a model for something equivalent, that supports current and future neutrino experiments at the Laboratory.

During Run 1 the Fermilab group's diverse physics analysis program covered the science drivers and was balanced between Higgs physics and searches for new physics. Based on this experience and the associated expertise, a coherent science discovery plan was outlined for Run 2. The PAC commends the Fermilab CMS group for their strong Run 2 physics plan, encourages the group to continue highlighting the unique contributions of their postdocs and other young researchers, and looks forward to Run 2 results from the group.

Fermilab hosts the US Tier-1 facility for CMS (the largest of all CMS T1's). Fermilab Computing is working on facility "elasticity" (cloud and HPC) that will be necessary for the future. Fermilab is involved in all aspects of CMS computing, including both software and hardware. The very successful CMS analysis framework is itself a product of Fermilab. 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.

Other Items

The Committee would like to request a full report on the FNAL Scientific Computing Division and its vision at the next PAC summer meeting.