Fermilab Physics Advisory Committee Meeting
2012 October 15-17

Comments and Recommendations

Introduction

The Fermilab Physics Advisory Committee (PAC) met at Fermilab at a remarkable time in both particle physics and the life of the Laboratory. Since our previous meeting, a fundamentally new particle with Higgs-like properties has been discovered at the LHC and the Dark Energy Survey has had first light. In the recent past, the value of $\sin^2(2\theta_{13})$ has been shown to be larger than many expected. Each of these historic developments, which are the result of decades of hard work and investment, have very positive impacts on Fermilab programs, and they promise a very bright future for particle physics. At the same time, funding continues to decrease, and both universities and laboratories are experiencing painful cuts. The dissonance between great success and relatively low funding priority of HEP is disturbing and difficult to understand by those of us, including laboratory staff, who devote their lives to physics. The current climate thus presents both challenges and opportunities for the Laboratory.

The PAC considered several issues regarding Laboratory scientific activities, two proposals, and three letters/expressions of intent (LOIs/EOIs). The PAC also heard updates on the Proton Improvement Program, the Muon Accelerator Program, the connections between Fermilab programs and the Snowmass 2013 process, LBNE, Mu2e, CMS, and DES. In addition, there were extended discussions about plans for a Spectroscopic Survey to address dark energy science.

The Committee greatly appreciates the time and effort required of the proponents and presenters to prepare the materials for this meeting. The excellent support of Hema Ramamoorthi is also very much appreciated.

The Committee also thanks the Fermilab Director for reporting on the overall status of the Laboratory programs and key issues facing the Management. The PAC welcomes Steve Geer, who has succeeded Jeff Appel as head of Program Planning.

Extended MiniBooNE Running: P-1032 and P-1033

The PAC heard a presentation on a possible Dark Matter (DM) search running the MiniBooNE experiment in a "beam off target" configuration (Proposal P-1032).

The PAC recognizes the potential value of the physics and appreciates the idea of performing an opportunistic measurement such as the one proposed. At the same time, the PAC is concerned about the remaining strength of the collaboration and the possibility that a hasty detour to search for dark matter will not produce a decisive result. In addition, the PAC is surprised that the collaboration has not yet completed the analysis of the existing MiniBooNE data looking for the DM signature off time from the beam spill, one of the core components of the P-1032 proposal that is already accessible. The PAC feels that this analysis should be completed for its own scientific value as well as to demonstrate the viability of the method. Therefore, the PAC does not recommend proceeding to Stage-I approval, but also notes that it could be possible to prepare for an unambiguous measurement that may be done in the future.

The P-1033 LOI suggests a modification designed to address the 3.8-sigma excess in the neutrino oscillation data originally observed by the experiment. The uncertainty on this measurement is limited by systematics, since the excess is concentrated in the low-energy region dominated by backgrounds from NC, in particular due to pion misidentification. The addition of 300 kg of PPO to 800 tons of mineral oil would allow observing the n-capture ($np \rightarrow d\gamma$) signal, which enables separation of the CC oscillation signal events from those due to NC backgrounds**.** The collaboration projects that, after collecting 6.5×10^{20} POT, the significance of the separation between the neutrino oscillation and background hypotheses would be about 3.5 sigma. Should the oscillation signal be confirmed, the result could increase the significance, possibly approaching the 5-sigma level. Again, the PAC is concerned about the remaining strength of the collaboration, and suggests that any proposal must convincingly show that a definitive measurement to elucidate the observed anomaly is possible. This would include more detailed studies of the detector performance with the enhanced scintillation, in particular its effect on e/pi separation and in view of the fact that the enhanced scintillation option was rejected in the original MiniBooNE detector design. In addition, the proposal must demonstrate the relevance of this measurement in light of the expected MicroBooNE running in the near future.

NNbarX

The PAC received an EOI for the NNbarX experiment. The proposed experiment would search for n-$\bar{n}$ oscillation in the first stage of Project X.

The observation of n-$\bar{n}$ oscillation would be a major breakthrough in particle physics, providing evidence for baryon number violation, which is needed to explain the observed baryon asymmetry of the Universe. The Standard Model can accommodate baryon number violation via non-perturbative mechanisms, which break both baryon (B) and lepton number (L) but preserve B-L. The study of n-$\bar{n}$ oscillation (a $\Delta B=2$ process) is complementary to that of proton decay, which would be a $\Delta B=1$ process. Such oscillation might therefore be related to the lepton sector, as the annihilation of Majorana neutrinos is a $\Delta L=2$ process: if L is broken by two units then it is natural for B to be broken by two units, too, and unified theories with Majorana neutrinos also predict n-$\bar{n}$ oscillation. However, there is no clear prediction for the scale of such oscillations, so the scientific case would be exciting, provided a large step in sensitivity could be obtained.

The previous state-of-the-art experiment (at ILL, Grenoble) provided the current lower limit on the n-$\bar{n}$ oscillation time of about 10^8 s. An interesting increase of sensitivity is projected for NNbarX, by a factor of 20–30 for a first proposed phase with a horizontal detector layout. A second stage with a vertical layout could give a further factor of 100, corresponding to probing the oscillation time up to 10^{10} s. The vertical layout would be more challenging to construct, but would allow the use of very slow neutrons (which would suffer excessive gravitational deflection in a horizontal layout). The main improvements in sensitivity reportedly come from increase of the neutron flux delivered to the annihilation target, optimized with super-mirrors or diamond nanoparticle reflectors, and from extending the observation time through increased length of the vacuum vessel or the use of slower neutrons. A dedicated spallation source would be required at Project X, a challenging design with cryogenic moderator surrounding the solid metal target.

The PAC recommends that R&D be supported, when possible, for the design of the spallation target, and for the overall optimization of the experiment, to bring it to the level required for a proposal to be prepared. The NNbarX experiment would be an interesting addition to the wider physics program involving neutrons at the first stage of Project X. The collaboration is encouraged to contribute to the Intensity Frontier sessions at the forthcoming Snowmass meeting.

Project X Physics Developments

As discussed at the last PAC meeting, budgetary constraints have led to the need for a staged approach to Project X. The first stage will feature a new superconducting 1 GeV linac, to replace the aging 400 MeV linac in the Fermilab accelerator complex. A more fully developed physics case for the first stage was previously requested by the PAC for this meeting.

The PAC received a document and heard a presentation describing the physics opportunities with Stage 1 of Project X. The physics case for the first stage is being developed over a wide range of topics at the intensity frontier, including the use of neutrinos (for oscillation studies), muons (extending the sensitivity of g-2 and Mu2e), kaons (for the ORKA rare decay program), hadronic physics (with potential for new experiments studying QCD), and searches for neutron EDMs, as well as nuclear energy applications.

The PAC commends the proponents on the clear articulation of the physics case for Stage 1. The breadth of the program is impressive. The staged approach to Project X should provide the opportunity for the first stage to proceed in a timely manner. Coordination with the nuclear physics field is encouraged for the definition of the plan for physics topics that touch both particle and nuclear physics interests, such as those involving slow neutrons. A well-focused R&D program is required for a number of the proposed experiments. The proponents are encouraged to submit detailed documentation of the physics case to the current Snowmass process.

Polarized Drell-Yan P-1027

In June, 2012, members of the SeaQuest Collaboration presented a proposal (P-1027) to the PAC for a Polarized Drell-Yan Experiment at Fermilab. P-1027 proposes to measure the "Sivers function" in polarized Drell-Yan by exposing the existing E-906 detector to a transversely-polarized proton beam. By testing that the Sivers function measured in Polarized Drell-Yan is of equal magnitude, but with opposite sign, to the analogous function measured by COMPASS and HERMES in deep inelastic scattering, this experiment would probe a prediction of perturbative QCD. This measurement is important to the nuclear physics community, and is of interest to the high-energy physics community as well.

At the time of the previous PAC meeting, the Committee was concerned that the new experiment could negatively impact the core programs at the Laboratory, and asked the proponents to provide additional information before considering a recommendation on the request for Stage I approval. During the summer, the collaboration addressed the questions raised by the PAC, and at this meeting presented a simplified beam design that requires only one Siberian Snake in the Main Injector. This solution significantly reduces the impact on the Fermilab neutrino program while preserving the levels of polarization needed by the experiment. This modification also results in substantial cost savings. The PAC commends the Collaboration for the excellent progress.

However, even with the simplified polarization scheme, the anticipated impact on NOvA

is not negligible. Moreover, the support needed to provide enough beam intensity and polarization to P-1027 would increase demands on the accelerator division, which would need to acquire the expert personnel to support the polarization program. Finally, the proposed funding model for the experiment (50% from Nuclear Physics and 50% from High Energy Physics) would require the laboratory to make a substantial investment.

Therefore, the PAC recommends Stage 1 approval, contingent on ensuring that full funding for the experiment be made available through nuclear physics, including support for expert accelerator personnel, and the understanding that the NOvA program has priority for protons should the intensity fall short of current projections.

Proton EDM

The PAC received an expression of interest for an experiment to measure the electric dipole moment of the proton with sensitivity at the 10^{-29} e-cm level. The present limit, about 10^{-26} e-cm, is inferred from the limit on the atomic electric dipole moment of Hg. The physics case for such a measurement is compelling since models with new physics at the TeV scale (*e.g.*, low energy supersymmetry) that have new sources of CP violation can give contributions of this order, if the electric dipole moment arises at the one- or two-loop level and the new CP violating phases are not too small.

This experiment was proposed to the Brookhaven National Laboratory in 2008, and underwent technical reviews in 2009 and 2011. The PAC was informed that the proposal was submitted to the DOE Office of Nuclear Physics, but no action has been taken. Substantial cost savings may be achieved by siting the experiment at Fermilab, where a suitable tunnel already exists. Sufficient proton intensity can be achieved by using the existing complex, however a polarized proton source is required.

This experiment represents an exciting opportunity for Fermilab. To make further progress, the project needs about two years of R&D. Although there are possible roles for Fermilab to participate in the R&D phase (*e.g.*, development of the electric field plates), the most critical element is the Beam Position Monitor, which is to be constructed and tested at Brookhaven. A demonstration ring may be capable of making an interesting measurement of the electric dipole moment of the proton at the 10^{-27} e-cm level, so it seems worthy of a detailed plan.

The PAC recommends that Fermilab and Brookhaven management work together, and with potential international partners, to find a way for critical R&D for this promising experiment to proceed.

LBNE Developments

As discussed in the previous PAC meeting report, the LBNE project has been reconfigured into stages, each satisfying constraints on both total cost and peak spending and having its own physics justification. The baseline for Stage 1 is a 10 Kt liquid-argon detector on the surface at Homestake.

At the June meeting, the PAC expressed concerns about the unresolved technical risk of operating a liquid-argon detector on the surface, due to the large flux of cosmic-ray induced airshower particles. The PAC requested updates on the progress managing and resolving this key technical risk. At this meeting, the PAC heard an encouraging report on the study of the effects of cosmic-ray backgrounds for the surface detector. The simulations indicate that these backgrounds will be manageable with <10% reduction in acceptance. However, the PAC believes that further work will be required to provide fully convincing results for this flagship experiment. In particular, the background rates should include estimates of the uncertainties. In addition, some statements were made at the presentation that the detector must be "slightly underground" to mitigate the effects of the cosmic ray flux. It would be desirable to understand such requirements in a quantitative fashion.

The presentation also mentioned that accurate timing information from scintillation light will be essential to reject backgrounds from the very high rate on or near the surface. The PAC would like to see more details of how this principle will be utilized and whether segmentation of the TPC (both for charge and light) will eventually be required. The PAC agrees that the operation of the 35t prototype liquid-argon detector and MicroBooNE will provide additional checks on these issues.

The PAC encourages the collaboration to concentrate, for the immediate future, on the task at hand: designing a viable detector able to perform the physics at the surface. The ultimate goal is a larger detector underground for both high-intensity neutrino measurements and the other physics topics (such as proton decay and supernova neutrinos). Furthermore, a near detector will be needed. The PAC encourages the parallel efforts of the LBNE collaboration, in coordination with the Laboratory, to secure additional domestic and international participation to enhance the physics reach of Phase 1 as much as possible, including an underground option.

Mu2e Progress

The Mu2e experiment is designed to detect the lepton-flavor-violating conversion of muons to electrons with single event sensitivity of 2×10^{-17}, a factor of 10^4 better than

previous measurements. This goal requires unprecedented beam intensities and control over backgrounds, as well as the construction of ambitious detectors and beam elements.

The PAC heard of progress on many fronts, including simulations in support of the design of critical systems. The collaboration has developed a suite of simulation tools, especially for neutron and cosmic ray studies, which are needed to inform a number of important detector decisions. The former are critical, as they influence not only detector designs but also beam, tunnel, and shielding parameters. A Neutron Task Force is working on many issues, including shielding calculations and a MARS-GEANT4 comparison.

Decision points are imminent on a number of technical fronts, including absorber configurations, tracker options, calorimeter designs, and beam extinction monitors. All are at advanced stages and at nearly the same level of detail, which should lead to well-informed choices in each case. The PAC understands that all of these decisions should be made by spring 2013, and the PAC looks forward to hearing the results during the June 2013 meeting.

Important measurements of particle and X-ray production in a stopped muon beam were planned at TRIUMF in November 2012, but this may be delayed, and PSI may be an alternative venue.

The three solenoids are on the critical path, and a conceptual design has been approved, which is a major milestone. A preliminary engineering design is the next step, with an advanced design required by early 2015. R&D on prototype conductors for the PS/TS/DT magnets will be done over the next year, leading to an important goal of CD3a approval at the beginning of FY14 (before CD2). This will allow for long lead-time conductor procurement and fabrication during the final solenoid engineering phase. Solenoid fabrication is scheduled to begin in mid FY15 and go into mid FY18 in parallel with detector and beamline construction.

The collaboration and the Laboratory are commended for the successful CD-1 last summer and for keeping all of the various development paths (beams, background/shielding calculations, detector designs, and magnet R&D) on schedule. The PAC notes that there are areas in which more effort would be welcome. The PAC looks forward to a full discussion of Mu2e status in June 2013, after key design choices have been made.

Muon Accelerator Program

The PAC commends Fermilab for conducting accelerator R&D applicable to both e^+e^- linear colliders and muon colliders, thereby positioning the Lab to play a role in a next energy-frontier machine, and for collaborating with CERN on the technologies needed for luminosity and energy upgrades of the LHC. The HEP community has just started an important planning exercise, a.k.a. Snowmass 2013. In view of the discovery of the new boson and Snowmass 2013, it is timely that the laboratory increases its effort to help develop a compelling physics case for a muon collider and to identify the critical issues that require significant R&D for the detectors.

CMS Upgrades and Author List Issues

The PAC congratulates the US CMS collaboration and Fermilab for the remarkable performance of the experiment and the discovery of a Higgs-like boson.

Fermilab continues to play critical roles, as US CMS enters a challenging period in which it completes the analysis of the data collected during the present run, supports the detector improvements planned for the first long shutdown (LS1) of the accelerator in 2013-2014, prepares for the construction of the phase 1 upgrades, and continues the challenging R&D necessary for the final phase of the upgrade when the large CMS silicon tracker and the forward calorimetry will need replacement. The PAC believes that it is critical that CMS is fully prepared for the exciting phase after LS1, when the LHC will reach design energy and also likely surpass design luminosity.

The PAC heard a status report on the phase 1 upgrade that includes the pixel detector replacement, the HCAL photo-detectors and electronics upgrade, and the L1-trigger upgrade. The CMS collaboration plans to conduct these upgrades before the second long shutdown (LS2) of the LHC planned for 2018. US CMS has played key roles in the completion of the Pixel and HCAL Technical Design Reports, which include a strong physics motivation for the upgrade. The two TDRs were recently presented to the LHCC and were endorsed without reservation. The TDR for the L1 trigger upgrade is currently being prepared, and it will be presented at the LHCC spring meeting.

The PAC welcomes the news that the CMS and ATLAS phase 1 upgrades have received DOE CD-0. The PAC recommends that the laboratory provide the necessary support for US CMS to complete the CD approval process successfully. This requires both selection of a project manager and a project support team as soon as possible. A strong engineering effort is also needed to guarantee quality and to handle integration issues.

The PAC has previously expressed concern that some US LHC scientists are excluded from being authors of scientific papers based on their source of funding. As the PAC wrote in the report from the June 2012 meeting, *"The Committee is concerned with recent developments that effectively preclude some US authors on LHC scientific papers based on their funding sources. Artificial separation between "operations" and "research" specialists can have a harmful effect on the whole field."* At this meeting the PAC learned that a small, but still significant, fraction of Fermilab CMS staff is affected. There is a concern that the separation between "operations" and "research" specialists could impair the ability of the Laboratory to fill positions that require specific expertise or managerial skills. The PAC hopes that the current discussion within the CMS Collaboration Board can find a workable solution that alleviates this problem.

DES

The PAC heard a presentation on commissioning and operations plans for DES, which very recently had first light. The PAC congratulates the entire DES team, and their supporting agencies, on this great accomplishment. The progress is excellent, and the PAC would appreciate a talk on early science results and an update on the status of the experiment at the summer meeting.

Spectroscopic Survey

The PAC heard updates on BigBOSS and DESpec, two compelling concepts for wide-field spectroscopic surveys using 4-m telescopes (the Mayall in the northern hemisphere and the Blanco in the southern hemisphere, respectively) to address dark energy science at Stage-IV sensitivity. The PAC also heard perspectives from NSF Astronomy, NOAO, and DOE, which were enlightening and very much appreciated. In its previous report, the PAC wrote,

"There are strong points to both projects and the Committee encourages the Laboratory to seek a consensus on a single proposal. Several upcoming events, including the NSF portfolio review, the determination of the starting date for LSST, and a 2013 Community Summer Study will change the landscape, and the time could be ripe for defining the next phase of dark energy science, including a unified redshift survey. In addition, a larger engagement of the Laboratory with LSST (currently proposed to start in 2014) should be considered."

The PAC reaffirms this advice, and notes in addition:

- The Portfolio Review recommended disinvestment from Kitt Peak telescopes, including the Mayall. The decisions about implementation of the recommendations will likely occur before December 2013, and possibly before June 2013. Should the NSF largely disinvest in the Mayall, it may be possible to find funding elsewhere to operate the telescope, but this remains uncertain. Dedicated observing time to BigBOSS would reduce the time to complete the survey.
- BigBOSS on the Mayall was selected by a non-advocate review process, under the assumption of continued operation by NOAO. A similar process has not occurred for DESpec, and there are currently no plans to do so.
- As the DOE presentation noted, "The ball is in the Agencies' court." If the two collaborations could together present unified options now, the process might simplify and the chances that the survey will happen in a timely way might increase. This would also likely optimize the overall science reach and speed up the definition of the project after the selection.
- The PAC also heard that Fermilab is in discussions with LSST about expanded hardware roles. Thus, in the area of dark energy, the Lab is engaged fully in DES, is ramping up on LSST, and is carrying forward work on two competing spectroscopic survey concepts. The PAC is concerned that the Laboratory may be stretched too thinly in this area and suggests careful thought be given to prioritization and timely decision making. The PAC requests a brief update on the Lab's plans for LSST, DESpec, and BigBOSS at its summer meeting.