June 29, 2012

Fermilab Physics Advisory Committee Meeting
June 19-23, 2012 – Aspen, CO

Comments and Recommendations

Introduction

The Fermilab Physics Advisory Committee (PAC) met in Aspen, Colorado, to consider several pressing issues regarding Laboratory scientific activities, one proposal, and three letters of intent (LOIs). A principal issue under discussion involved the laboratory's plan for pursuing the long-baseline neutrino program in light of DOE's recent communications indicating that the Long Baseline Neutrino Experiment (LBNE) must be a phased program with substantial physics output at each stage. The PAC received a presentation on and discussed the detailed report of an ad hoc committee (LBNE Reconfiguration Steering Committee) which recommended several options for pursuing LBNE in a phased approach, as well as reports from the LBNE Collaboration and from two working groups, one on the physics reach of each option (LBNE Reconfiguration Physics Working Group) and the other on cost considerations (LBNE Reconfiguration Engineering/Cost Working Group). In addition, the PAC discussed the GLADE LOI which addressed another long-baseline neutrino opportunity.

Another significant topic under discussion centered on short-baseline neutrino oscillation experiments and other related indications of possible anomalies at odds with the current three-neutrino mixing picture. The PAC received and discussed a report from a focus group established by Fermilab which examined the short-baseline neutrino-oscillation situation and recommended possible paths leading to resolution of the anomalies. Two LOIs, LAr1 and νSTORM, aimed at addressing the apparent anomalies, were presented and discussed by the Committee.

Fermilab's plans for pursuing the Intensity Frontier with Project X have also been modified recently to incorporate phasing of the accelerator and physics program to accommodate constrained budgetary projections. The Committee heard presentations on the technical and scientific prospects for the phased Project X program. In addition, the PAC received presentations on the currently planned muon program including the g-2 and Mu2e experiments, and on the ORKA experiment, a precision measurement of $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ decay, which was granted Stage I approval after the previous PAC meeting.

The proposal for a Polarized-Proton-Beam Drell-Yan Experiment was considered for the first time at this meeting. It involves development of new polarized beam capabilities at Fermilab and use of the existing SeaQuest apparatus. The Committee discussed this proposal and suggested several areas for further investigation.

The Committee also heard status reports dealing with other important aspects of the Fermilab program including the Energy Frontier experiments, Cosmic Frontier activities, accelerator development and operations, detector R&D, and neutrino factory/muon collider development. The Energy Frontier experiments are proceeding actively to determine the Higgs mass and to search for new physics. Announcements from the LHC experiments dealing with the Higgs search are reported to be imminent.

Planning for Fermilab's role in the future of high energy physics was also discussed along with a presentation regarding the next "Snowmass" community planning exercise. The PAC discussed concerns about the uncertainties in the LBNE project and its impact on planning for other significant aspects of a diversified scientific program at Fermilab. This uncertainty has affected the PAC's evaluations of virtually every aspect of the future experimental portfolio of Fermilab.

The Committee greatly appreciates the time and effort required of the proponents and presenters to prepare the reports for this PAC meeting. The Committee also thanks the Fermilab Director for reporting on the overall status of the Laboratory programs and key issues facing the Management. On the occasion of the approaching retirement of Jeff Appel, the PAC wishes especially to thank him for his dedicated and effective service to this Committee and to Fermilab.

The following comments and recommendations relate to the pressing issues above, the proposal, the three LOIs, and other issues raised by the presentations.

Long-Baseline Neutrino Experiment (LBNE)

The PAC reaffirms its strong endorsement of the physics goals of the Long-Baseline Neutrino Experiment (LBNE). The observation of CP violation and determination of the mass hierarchy for neutrinos are key missing pieces in the puzzles of the fermion masses and the origin of the observed baryon asymmetry in the Universe. A large liquid-argon detector, if sited underground, would also provide significant reach in the search for proton decay, as well as detailed information about neutrinos emitted from supernova explosions. The large observed value of $\sin^2(2\theta_{13}) = (0.092 \pm 0.016\ \text{(stat)} \pm 0.005\ \text{(syst)})$assures that the physics goal of measuring CP violation is achievable if the phase is not too close to 0 or π.

As a consequence of the March 19, 2012, letter from the DOE, Fermilab has been leading an intense effort to reconfigure the LBNE project into stages, each satisfying constraints on both total cost and peak spending and having its own physics justification. The Committee is impressed with the effort by the Laboratory and the LBNE Collaboration in preparing staged options, using strong community involvement, on an extremely short time-scale. A national Steering Committee, with Working Groups for physics and engineering/costing, has produced a draft interim report that finds three viable options under the tight constraints: (1) a 30 kT surface detector at Ash River (810 km) using the NuMI off-axis (narrow-band) beam, (2) a 15 kT 2,340ft- underground detector at the Soudan Laboratory (735 km) using the NuMI on-axis (wide-band) beam, and (3) a 10 kT surface detector at Homestake (1300 km) with a new beam line. Excellent presentations of the physics considerations for the options in an international context, the engineering/cost issues, and the reaction of the LBNE Collaboration were given to the PAC.

The PAC concurs with the analysis of the pros and cons of each option as presented in the Steering Committee report. The PAC further agrees that if additional funds ($135M current estimate) were available to place the 10kT detector underground at Homestake, the Phase 1 program would be greatly enhanced.

The PAC also concurs with the Steering Committee's inclusion of the unresolved technical risk of operating a liquid-argon detector on the surface, due to the large flux of particles from cosmic rays. Despite the optimistic initial estimates, this remains a key technical risk that must be managed and resolved. A large reduction in the fiducial volume would make the experiment unviable. Therefore, the PAC recommends that the underground options (Homestake and Soudan) be maintained, at least until this risk has been retired. The PAC recommends that the Laboratory and the LBNE Collaboration move as quickly as possible to answer this key question. The PAC would appreciate updates on the progress as new information becomes available.

The PAC reiterates that the ultimate goal -- a large detector underground for both high-intensity neutrino measurements and the other physics topics noted above -- is only fully realized in Phase 2. Concerns were expressed by PAC members that the beginning of Phase 2 is pushed far into the future in the staged program. The PAC also concurs with the Reconfiguration Report that a near detector is essential for full understanding of the physics of neutrino oscillations, particularly in case the data suggest new physics, *e.g.*, sterile neutrinos. Therefore, the PAC encourages the Laboratory and the Collaboration to seek additional domestic and international partnerships to enhance the physics reach of Phase 1. Committing to a steady direction is necessary to enable a broad international effort on neutrino physics at Fermilab.

GLADE LOI (P-1029)

The proponents of the Global Liquid Argon Detector Experiment (GLADE) LOI presented an idea to install a 5 kt liquid-argon detector in the same hall as the NO**v**A far detector. The addition of GLADE to NOvA, T2K, and reactor experiments would enhance sensitivity to the neutrino mass hierarchy. As such, the contribution of GLADE would be most significant if it could run concurrently with NOvA. In the long term this plan is not competitive with the proposed options for LBNE. An experiment of this type could become an interesting option if the current plan for LBNE is not realized.

Project X

Project X is the centerpiece of the Fermilab strategy for the development of a world-leading Intensity Frontier program. It would provide a high-power proton source enabling the study of neutrino oscillations, rare processes (for kaons, muons and neutrons), nuclear physics, and nuclear energy applications, while providing a path towards a future neutrino factory or muon collider. Budgetary constraints have led to the need for a staged approach, with each stage costing significantly less than $1B, each stage with compelling physics opportunities, and using existing elements of the Fermilab complex where possible.

The PAC received a document describing the proposed Project X performance by stage, and heard presentations on the phasing of Project X, and on its physics, given remotely from the physics study workshop that was proceeding in parallel. The three proposed stages consist of first replacing the existing 400 MeV linac with a 1 GeV CW superconducting linac with the capability of delivering flexible beam formats to multiple experiments; second, extending the CW linac to 3 GeV; and finally completing the reference design with a pulsed linac for acceleration to 8 GeV. A fourth stage, going beyond the Reference-Design-Report performance, is also under discussion.

The PAC understands that the physics case for each stage is a work in progress and must be further developed. Stage 1 will provide an increase of Main Injector beam power by up to 70%, from 700 kW to 1.2 MW, of significant interest for the long-baseline program at NOvA and LBNE. Nevertheless, this application uses only 2% of the available power. Another ~8% might be used to increase the power to the Mu2e experiment, but the practical value must be better understood. The PAC recommends that the physics case be strengthened through further investigation of potential Stage-1 applications, such as the neutrino and muon programs, and neutron EDMs. Other ideas, such as hidden-sector searches and muon cooling, should also be investigated and clearly articulated. The PAC looks forward to hearing a more fully developed physics case for Stage 1 at its next meeting.

Enhanced power for kaon physics will be possible at Stage 2 when the beam energy is increased. At Stage 3, at least 2 MW of beam power will be available at an energy of up to 120 GeV for the long-baseline neutrino program. Good progress is being made in the study of siting options for each stage. PXIE (the Project X Injector Experiment) is a program of system tests for the front end of Project X. It is considered by the PAC to be well conceived and is strongly supported. It will give impetus to the development of this rich program.

Polarized Drell-Yan Measurements with the Main Injector (P-1027)

Members of the SeaQuest Collaboration presented their proposal (P-1027), an experiment to expose their E-906 detector to a transversely-polarized proton beam. The goal of the experiment is to measure the “Sivers Function” by comparing polarization asymmetries in the Drell-Yan process, a high priority measurement in QCD. The polarized Drell-Yan process is thought to be the cleanest of many competing determinations of this quantity. The proponents emphasized that Fermilab is the best place to make this measurement. The P-1027 Collaboration proposes a fabrication and installation schedule to begin in 2013, with data taking to commence in 2015. The requested exposure is likely to be two years.

Although the SeaQuest detector would be reused in P-1027, numerous modifications to the Main Injector, Booster, and Linac will be required in order to produce a 70% transversely polarized beam directed to an unpolarized hydrogen target. Nevertheless, P-1027 is a natural way to capitalize on the investment made in SeaQuest, and cooperation between the DOE Offices of Nuclear Physics and High Energy Physics is valuable.

As proposed, P-1027 could significantly impact the core programs at the Laboratory. Even with this concern in mind, the PAC can imagine a scenario in which impacts on the core program might be minimized.

The PAC has concerns, and would like answers to some questions before being able to consider making a recommendation on the request for Stage I approval.

Questions for P-1027

1. Running with two Siberian Snakes in the Main Injector would impact the core Fermilab program as one of them would require removal of the NOvA extraction kickers. What would the reduction in polarization be with one MI snake and what would be the quantitative effect on the goals of the experiment?
2. In-kind and M&O contributions from outside of Fermilab sufficient to mount and sustain the experiment would be necessary in order to recommend approval, and the budget model needs to be fleshed out in greater detail with the DOE ONP, OHEP, and NSF. What arrangements can be made to secure outside funding?
3. There are two estimates for Snake fabrication and they vary widely. What are the anticipated costs for snake fabrication?
4. What are the likely impacts on the Fermilab infrastructure and expert personnel in the installation and commissioning of the components of the proposed polarized-proton beam in this system?
5. What are the likely resource and infrastructure implications for operating such a beam?

Short Baseline Neutrino Experiments

The PAC heard a presentation and received a report from the Short-Baseline Neutrino Focus Group established by Fermilab. Following a suggestion in the December 2011 PAC report, Fermilab responded rapidly to define a strategic plan for short-baseline neutrino physics. The report outlined that several neutrino oscillation experiments have produced hints that do not seem to fit within the simple three-flavor mixing framework. These tensions might be purely statistical in origin, or might arise from one or more unidentified systematic effects or from new physics. The Focus Group report established a valuable baseline for evaluating the extent to which ongoing and planned neutrino experiments will be able to determine the origin of these anomalies. The report also addresses competing facilities and future capabilities at Fermilab for supporting a short-baseline neutrino program to definitively resolve these questions, and suggests what the criteria for an optimal short-baseline neutrino program might be beyond the presently approved and running experiments.

The Focus Group made a number of recommendations promoting new experiments to deal definitively with the short-baseline neutrino-oscillation issue. Among them is the compelling statement that any new short-baseline proposal should clearly demonstrate in detail the ability to discover, or exclude (with at least 5σ significance), sterile neutrinos over the entire parameter space indicated by the LSND and recent MiniBooNE results. The PAC considers that any new experiment should address appearance and disappearance phenomena. In addition a new experiment would be better justified if the physics case for sterile neutrinos is further enhanced by new measurements from MicroBooNE, MINOS+, reactor, or radioactive sources.

The PAC received two LOIs dealing with possible new short-baseline neutrino-oscillation experiments: LAr1 and νSTORM.

LAr1 LOI (P-1030)

The PAC heard from the proponents of the LOI for LAr1. The concept of this experiment is to place a one-kiloton-scale liquid-argon detector in the Booster Neutrino Beamline at ~1km from the target and to use the MicroBooNE detector (re-positioned) as a near detector, to address the sterile-neutrino hypothesis as the solution of the LSND/MiniBooNE anomaly. Preliminary sensitivity plots for ν_μ-to-ν_e appearance were shown for neutrino and antineutrino modes. The PAC recognizes the advantages of the two-detector approach and the potential benefit of the liquid-argon-detector technology for this physics. The PAC has concerns on the following issues: how development of this one-kiloton-fiducial-volume detector fits in with the liquid-argon-detector development for LBNE; the precision of the estimated systematic uncertainties for the ν_e-appearance sensitivity plots; the sensitivity for addressing both the LSND and MiniBooNE anomalies; and the capability of definitively addressing the disappearance channels.

νSTORM LOI (P-1028)

The PAC heard and discussed the νSTORM letter of intent. The experiment would consist of a muon storage ring to produce a neutrino beam from 3.8 GeV-muon decays, and of a 1000-ton-scale magnetized-iron far detector located approximately 1.5 km away from the ring. This configuration, based on an old, but never implemented idea, would provide an ideal setup to study eV-scale oscillation physics in appearance and disappearance modes, and to measure electron and muon neutrino cross sections with an unprecedented precision. The envisioned facility offers opportunities for extensions, such as adding a cooling channel and opening the path towards neutrino factory technologies. The presented baseline design envisions a new 60 GeV, 100 kW target station, followed by a collection/transport channel and a decay ring. A cost estimate was presented, and the required investments are significant.

A clear set of parameters for the various accelerator components and schemes, backed up by beam-transport simulations, and the corresponding achievable performances were presented. Assuming 1×10^{21} protons on target are achievable in 5 years, the neutrino event rates are impressive, even in a 1000-ton detector. Each accessible-flavor neutrino (ν_e and anti-ν_μ, or anti-ν_e and ν_μ) would produce several hundred thousand events in the far detector and several million events in a near detector approximately 50 m from the decay ring. The baseline magnetized-iron detector (SuperBIND) offers a reasonable approach for studying muon final states.

The event reconstruction efficiency of the SuperBIND depends sharply on the energy in the region of interest and drops significantly at the lower range. A further optimization of the detector and of the reconstruction method might help to recover lower-energy events. A low probability of muon-charge misidentification and a high event rate would provide a clean environment to probe electron-to-muon neutrino oscillations.

The combination of a clear resolution of the short-baseline neutrino anomalies, the precise measurements of the neutrino cross sections, and the synergy with neutrino-factory technology makes this a potentially attractive project.

Overall Intensity Frontier Strategy

Over the past six months, it has become clear that both LBNE and Project X must be phased programs. There has been intense parallel activity in both these areas. The PAC commends the Laboratory for its strong leadership and execution in dynamic circumstances.

One interesting result is the possibility of interleaving the phases of these projects so that Phase 1 of Project X could start significantly earlier than previously foreseen.

However, the resulting stretched timescale due to budgetary limitations is a concern. To deliver physics as soon as possible, the PAC encourages the Laboratory, in close consultation with the various interested community groups, to look for opportunities to optimize the phasing to make these programs mutually beneficial as the phases are interleaved.

In the current notional timeline, Phase 2 construction for either project would not be complete until 2030 or later. This long timescale has several important implications:

- The physics cases for each phase must be independently compelling at the anticipated timescales, with particular emphasis now on the physics case for Phase 1.
- It is essential to continue to press the importance of the later phases.
- The reliability of aging infrastructure must continue to be assessed as the details of the phasing are formulated.

The PAC urges that the updated physics cases for the phased programs be intensively discussed as soon as possible with the rest of the particle physics community, starting with those working at the Intensity Frontier, as well as with the broader scientific community.

Finally, the PAC appreciates the efforts of the Laboratory towards realizing a diverse program, and encourages continued efforts to maintain opportunities for high-priority smaller projects even as the very large projects proceed.

Cosmic Frontier

The PAC was impressed with the Fermilab program at the Cosmic Frontier. The program is well balanced, with careful choices of high impact projects that are aligned with the DOE mission and consistent with a tight-budget environment. The Fermilab Cosmic Frontier program also has considerable accomplishments to report.

Dark Energy

The study of dark energy accounts for over half the program. The Sloan Digital Sky Survey continues to produce important results. The $35M Dark Energy Camera (DECam) has been completed according to specification, as marked by successful completion of DOE Start of Operations, CD4. The camera has been shipped to Chile and is currently being installed on the Blanco telescope. This is an impressive accomplishment, for which the whole team should be congratulated. The immediate challenges include commissioning the camera, performing the scientific verification, and beginning the survey by the end of the year. Over the next five years, photometry on 300 million galaxies and 4000 supernovae out to z~1 will be performed. The plans for data management have had to be revised. There is a temporary pipeline for the initial survey to be followed by a more permanent arrangement. The PAC looks forward to an update on progress on this schedule at its next meeting.

The natural next step for the Laboratory would be to participate in a ten-million-redshift spectroscopic survey to z~1. The two potential projects are DESpec, led by Fermilab, and BigBOSS, led by LBNL and in which the Fermilab group has a small involvement. 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.

Dark Matter

The Laboratory is involved in three dark matter experiments, CDMS, COUPP and DarkSide. The Laboratory has started to address the manpower concerns expressed in previous PAC reports.

A selection process is starting at the national level. The underground-science competition at NSF and Generation-2 Dark-Matter R&D competition at DOE this year will lead to project proposals in October 2013 and a second selection stage in 2014. It is important for the Laboratory to provide enough scientific and engineering support to the selected teams this year, potentially rebalancing the current distribution of effort, to augment the teams' chances at the project selection stage.

In addition to the program described above, the innovative small DAMIC experiment is searching for very-low-mass WIMPs .

Cosmic Rays

Fermilab's involvement in the Auger project is ramping down. The remarkable success of this project towards resolving the GZK controversy is noted. It is anticipated that the composition of the ultra-high-energy cosmic rays will be determined soon.

Holometer

There has been rapid progress on this ambitious investigation of physics at the Planck scale. The experiment's goal is to set a sub-Planckian limit on quantum noise within two to three years. If a positive measurement is made, which can be shown to be fundamental, this discovery will initiate an exciting and major new research field. In either case, the developed technology may find other uses, such as for axion-like particle searches.

Cosmic Microwave Background

With successful completion of QUIET-1 there is no plan for future involvement in this research area. However, there might be another opportunity in the future for developing a national program in which Fermilab could play an important role.

Energy Frontier

With the Tevatron Collider data taking period ended, the CDF and DZero collaborations are working on finishing key analyses. These groups continue to produce important physics results and PhD theses. The Committee is happy to see that the Laboratory is providing the necessary support, especially for computing and visitors, to ensure a timely completion and publication of the relevant physics results. The Committee supports the effort to develop a strategy for data preservation.

With the energy frontier shifting to the LHC, Fermilab has been very effective as a host laboratory for CMS. The LHC Physics Center, LPC, is a valuable resource for the entire US CMS community. The fellowship program is essential in keeping the vibrant group on site. Fermilab scientists are playing key roles both in the CMS Collaboration management and in physics groups. Fermilab physicists are major contributors to a large number of CMS publications. Fermilab's role is critical to ensure a US prominent role in the CMS upgrade.

Fermilab hosts a CMS Tier 1 computing site which is key to timely data processing and is important to ensure a direct access to data by the US collaborators. The Committee encourages the Laboratory to continue its support for CMS computing. The LPC and the well-organized test beam facility at Fermilab are essential components in maintaining the Laboratory's connection with the CMS user base.

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. The PAC would be interested to hear about the implications of these decisions on the Fermilab staff.

LHC experiments are reshaping the particle physics landscape. The Committee compliments Fermilab for ensuring its role in a next energy-frontier machine by pursuing accelerator R&D applicable to both linear and muon colliders and by collaborating with CERN on the technologies needed for luminosity and energy upgrades of the LHC.

Other Topics

Tevatron Operations

The PAC heard a final summary of the remarkable Tevatron Collider running with both record peak (> 400/μbarn/s) and integrated (>11.8/fb) luminosities delivered from FY2002 through FY2011. The overall Tevatron performance was a stellar achievement for Fermilab and the Department of Energy.

Neutrino Operations

Neutrino delivery to MINOS, MINERvA, and the NOvA Near Detector on the Surface in FY2012 was above projections following the resolution of the NuMI target problems of last year. A re-engineering of the cooling system led to a more reliable target with no leaks. A retuning of the Main Injector after Tevatron operations ceased led to a factor-of-two reduction in beam losses and the subsequent FY2012 proton delivery exceeded 2.5×10^{20} protons on target (POT) for a total of 1.6×10^{21} POT over the full MINOS run. This ends the approved MINOS run.

Booster Neutrino Beam performance to MiniBooNE in FY2012 also exceeded expectations, with a total of 1.5×10^{20} POT, which resulted in a doubling of the number of antineutrino events. The total delivery for MiniBooNE exceeded 1.5×10^{21} POT – above expectations. This ends the MiniBooNE run.

SY120 Operations

Operations for SeaQuest involve slow extraction of the Main-Injector beam for the first time at high intensity. The test beam area has run with 10^{11} protons per spill, while SeaQuest requires 100 times that rate. The engineering-period running for SeaQuest took place during the spring of 2012, but both beam pipe vacuum and beam spill quality problems were encountered which made commissioning difficult. The vacuum problem was dealt with in the short-term and a pipe insert can eliminate problems when the program resumes. The beam quality issues require a more sophisticated feedback system which will be worked on during the shutdown. Delivery of high-quality beam to this experiment will be a challenge.

Proton Improvement Plan

Some important pieces of the Fermilab beam system are four decades old and the Proton Improvement Plan (PIP) has been initiated in order to support the larger proton-intensity demands of the scientific program beyond 2013. This ambitious program happens within a severely limited budget.

The most urgent replacement is that of the forty-year-old Cockroft-Walton source with an RFQ injector system scheduled for this fall. A newly-received RFQ is just beginning shake-down and quality-control testing. There are indications of an energy loss outside of manufacturer specification, and the vendor is involved in trying to understand the source of the losses.

Likewise the Linac is quite old and at risk because of a single-source vendor for the 200 MHz RF power tubes. Multiple options are being investigated for replacement. These are but a few of nearly a dozen PIP projects scheduled for the Linac and the Booster.

The NOvA project includes upgrades to accelerator and neutrino beam systems (ANU). The upgrades include reconfiguration of the Recycler Ring as a pre-injector to the Main Injector, refurbishing of many magnets, installation of new RF systems and kickers in various locations, and necessary improvements to the very radioactive target hall. The first new sophisticated graphite target for NOvA has been received from the Rutherford Appleton Laboratory in the United Kingdom. This work is just beginning, and is scheduled for completion by February 2013.

Finally, the PAC heard of the highly utilized and important test-beam capabilities in the Meson Area. Protons, pions, electrons, and muons are available, and more than 200 researchers made use of the facility in the seven-month FY2012 run. The test beam was also a popular feature of the EDIT school in February 2012.

The PAC is aware of the effort that is required in order to upgrade the complicated Fermilab accelerator systems and to deliver numerous high-quality beams in support of the physics program. To date, the ANU and PIP projects are on schedule. However, there is a severe limitation in funds for PIP and the PAC is concerned that this will severely impact the program.

Muon Accelerator Program

The Fermilab Muon Accelerator Program (MAP) is focusing on the development of two future accelerators: a muon collider designed to explore the Energy Frontier, and a neutrino factory designed to explore the Intensity Frontier. The two programs share R&D and utilize the same front-end muon source.

During the initial phase of the project, the main priority of MAP is to establish conceptual feasibility of a multi-TeV muon collider. Such a machine has some advantages with respect to an electron-positron collider because the larger mass of the muons suppresses synchrotron radiation and beamstrahlung, thus allowing for higher center-of-mass energies and better beam-energy resolution. On the other hand, many technical challenges need to be resolved before a muon collider can become a reality.

In the past year, substantial progress was made on the development of several key components of a muon collider. The proof of principle of a liquid-mercury jet target was achieved by the MERIT experiment at CERN. The ionization-cooling technique is developing in the context of the Muon Ionization Cooling Experiment (MICE) at the Rutherford Appleton Laboratory, where past issues with the spectrometer solenoids and coupling coils seem to have been understood. Additional progress has also been made on the development of cavities, vacuum RF, high-pressure RF, and high-field magnets.

Some steps forward were also made in terms of detector simulation and physics studies, in particular in the context of the Telluride Muon Collider workshop in the summer of 2011. However, the momentum on this effort has substantially decreased over time.

The PAC congratulates the MAP group for their achievements in accelerator R&D during the past year. However, the Committee is concerned about the progress in detector simulation and physics studies since the Telluride Workshop, and suggests that a parallel effort of preparing for the 2013 Community Summer Study be mounted for muon collider physics as is being done for the neutrino factory. The Committee therefore recommends enhancing the present level of effort in this field by revitalizing the collaboration with other institutions and laboratories.

ORKA

The purpose of ORKA (P-1021) is to search for new physics beyond the Standard Model by measuring the branching ratio of $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ with a breakthrough sensitivity capable of collecting 1,000 Standard Model signal events. The Standard Model prediction of the branching ratio is expected to be understood at the level of several percent uncertainty with improved measurements of CKM parameters by current and future B-factory experiments. This makes the measurement extremely sensitive to the effects of new physics beyond the Standard Model. Together with measurement of the $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ branching ratio, which is sensitive to the imaginary part of V_{td}, there can be a wide-open exploration of an unambiguous phase space for new physics. These searches are complementary to the direct new-particle searches at the LHC, and the physics case is strong.

In the past, the BNL 787/949 experiments collected seven events in total, and measured the branching ratio $BR(K^+ \rightarrow \pi^+ \nu\bar{\nu})$ = $(1.73^{+1.15}_{-1.05})\times 10^{-10}$, using a stopped-$K^+$ technique to simplify kinematics and particle identification. Currently, the CERN NA62 experiment is preparing to collect of order 100 $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ events at the Standard-Model-predicted rate over the next five years, using a complementary technique of in-flight decay with an intense, un-separated beam. The J-PARC E14 KOTO experiment will start taking data next year to search for the neutral partner, $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ decays. ORKA plans to use the well-proven, stopped-K^+ technique, with a high-intensity proton beam from the Main Injector and improved detector components increasing the acceptance.

At the December 2011 meeting, the PAC encouraged the Laboratory and the Collaboration to explore how ORKA could proceed, even in a severely constrained budget environment. Several issues were identified, including siting of the experiment and the slow extraction from the Main Injector at the needed 5×10^{13} protons per spill.

Since the December PAC meeting, a task force was formed to analyze the cost and technical issues for preserving the option of installing the ORKA detector in the CDF collision hall, which is the preferred site. The Laboratory has decided to move forward to preserve this option, which the PAC welcomes. The PAC also heard that new groups are interested in joining the experiment.

The PAC again strongly encourages the Laboratory and Collaboration to move forward with the remaining studies necessary to assess how this important experiment can be done and on what timescale.

Muon Experiments

The PAC heard a presentation on the development of the Muon Campus, providing a common infrastructure that is designed to reduce the total costs of the g-2 and Mu2e experiments, while also keeping an eye toward future opportunities. The PAC commends the Laboratory for this development.

Concerning Mu2e, in its December 2011 report the PAC wrote:

> *The Committee encourages the experiment to continue to quantify the risks associated with uncertainties in sensitivity and background projections, making measurements where possible, and to put mitigation plans into place as early as possible to avoid erosion of discovery capability. The Committee also recommends that the Laboratory pay particular attention to ensure that the project is ready for effective reviews.*

The PAC was told that the recent Lehman review of Mu2e was successful, which reflects very well on the Collaboration and the Laboratory. As this is a challenging experiment, the PAC recommends continued careful attention by the Laboratory to Mu2e and requests updates on the progress at future meetings.

Generic detector R&D

Generic detector R&D is an important component of the service role of the Laboratory. The three major activities, representing roughly two thirds of the budget, are the ASIC development including 3D structures, the liquid-argon development, and the test beams. The PAC was pleased with the effort of Laboratory management to address the criticism expressed at the time of the last laboratory generic-detector R&D review by DOE. More rigorous management with an internal advisory group, which meets monthly, has been put in place. Some of the seeded programs of the past have been terminated and some successful activities like COUPP have become approved projects. The liquid-argon R&D has been strengthened, and is starting to produce impressive results relevant to LBNE; e.g., in the areas of liquid-argon purity and ^{39}Ar -depleted argon. The 3D ASIC development also appears to be very promising, and Si-PM R&D is progressing well. A detector R&D workshop was organized in December 2010. The Laboratory is also participating in the DPF Task Force on Instrumentation in High Energy Physics and is now better connected to the outside community.

It is important to continue strengthening the oversight of the detector R&D program and to make it more accessible to a wider community, including support for R&D aimed at the next generation of existing projects. In addition, the Laboratory may also want to define an explicit seed program to explore novel ideas.

The PAC supports the Laboratory's plan to include outside scientists as members of the Coordinating Panel for Advanced Detectors (CPAD) in the R&D advisory group.

Liquid-Argon R&D Program

The PAC heard a report on the liquid-argon detector R&D program, including components related to the ArgoNeuT experiment, the Liquid Argon Purity Demonstrator (LAPD), Long Bo (a long-drift-distance test), the development of cold electronics, the 35-ton membrane-cryostat prototype, MicroBooNE R&D, the argon distillation column, and a possible liquid-argon-detector beam test. Notably, the LAPD demonstrated sufficiently long electron-drift lifetimes in a large un-evacuated vessel. Future work will aim to establish the feasibility of the membrane-cryostat technique currently planned for the large scale LBNE detector. The liquid-argon beam test will attempt to determine experimentally the energy-resolution and particle-identification capabilities of a liquid-argon Time-Projection-Chamber (TPC) detector. The PAC was impressed by the depth and quality of this research program which has contributed to several important developments and is an integral component of the efforts to establish the future viability of large-volume liquid-argon TPCs for LBNE and other applications.