Office of High Energy Physics

Report on the
Fermi National Accelerator Laboratory
2013 S&T Review

November 5-7, 2013

Executive Summary

The Fermi National Accelerator Laboratory (Fermilab) Science and Technology (S&T) review was held on November 5–7, 2013 at Fermilab. The review was originally scheduled for September 10–12, 2013, but was moved to allow the lab's new director, who assumed his position on September 3, to have input to the lab's presentations. The goal of the review was to assess the current performance of the facility, the science resulting from the experiments that are served by the facility, including the CDF and D-Zero detectors of the decommissioned Tevatron, and plans for future improvements to the accelerator complex and all other beams provided to experiments. The panel was also asked to evaluate the facilities and support that Fermilab provides to the U.S. CMS user community. Following up on issues raised at past S&T reviews, the review panel was also asked to comment on Fermilab's progress toward becoming the premier intensity frontier laboratory in the world, the coherence of the Fermilab intensity frontier program and the planning and computer support for the various intensity frontier experimental initiatives at the lab. As part of this review, the laboratory was asked to present its proposed performance metrics for the NuMI neutrino beam in FY 2014.

HEP asked the review panelists to evaluate the lab using these criteria:

- The quality and significance of the laboratory's recent scientific and technical accomplishments; and the merit, feasibility and projected impact of its future planned physics program;
- The effectiveness and efficiency of facility operations, and the planning for future facility upgrades to support the research program including appropriateness of the proposed performance metrics in terms of being realistic and maximizing the scientific productivity of the facility;
- The effectiveness of laboratory management in strategic planning, developing appropriate core competencies, implementing a prioritized and optimized program, and promoting and implementing a safe work environment;
- The leadership, creativity, and productivity of the facility's scientific and technical staff in carrying out the above activities; and
- The quality and appropriateness of the laboratory's interactions with, and nurturing of its scientific community.

In general, the review panel found areas of technical and scientific strength within the Fermilab program. However, the review panel also raised several concerns and presented three recommendations to management.

1. **The review panel recommended that the lab formulate a coherent plan for its small and mid-scale neutrino experiments, which should include a timeline for physics and technical milestones.** The reviewers did not find the suite of neutrino experiments to be adequately coordinated into a program that had decisive physics goals that lend support to the lab's flagship experiment, the Long Baseline Neutrino Experiment (LBNE).
2. **The review panel recommended that the lab should develop a systematic comparison of the two or more linac upgrade options to reach the MW power goal.** The plan should

address what R&D is needed and when, the cost, the role of international contributions, any necessary infrastructure additions or upgrades, and the upgrade potential of the design. They should determine the implications for the ongoing PXIE and SRF work.

3. The reviewers requested the Scientific Computing Division to develop a plan for supporting software and computing needs for the neutrino experiments which will fully engage and leverage other DOE national labs' expertise and resources. The plan must enable distributed simulations, data management, and analysis and should include a set of metrics to gauge the success of the plan based on user experiences, both on and off site. The plan should call out any re-prioritization and re-allocation of resources in the Scientific Computing Division needed to align the computing support manpower with Fermilab priorities, as is being done in the accelerator, detector, and research areas.

Introduction and Background

With the shutdown of the Tevatron on September 30, 2011, Fermilab ended its mission as a leader of the energy frontier and embarked on its new role aimed at becoming the world-leading laboratory in the intensity frontier.

In order for Fermilab to become the world-leading laboratory engaged in the intensity frontier, it must develop a complex of reliable, high-intensity proton accelerators to create high intensity secondary beams of neutrinos, muons, etc. The Fermilab accelerator complex consisting of a Main Injector (MI) and Recycler, Linac and Booster, has produced neutrino beams for the MINOS and MINERvA experiments, and a neutrino beam for the MiniBooNE experiment. The MINOS experiment has produced world class data on neutrino oscillations, MINERvA has improved the accuracy of neutrino-nucleus cross section measurements which are important inputs to the analysis of many neutrino experiments and MiniBooNE has found evidence of anomalies in neutrino oscillation data, including hints of the existence of sterile neutrinos.

However, the aging accelerator complex and associated infrastructure put into question the attainability of Fermilab's plan to develop into the world leading laboratory in intensity frontier experimental physics. The lab has begun a multi-year effort to address these concerns, the Proton Improvement Plan (PIP), whose goal is to more than double the intensity of the proton beams delivered by the complex by FY 2016 by refurbishing or updating components that have been in use for almost 40 years. PIP activities are underway now and were particularly intense during a yearlong shutdown of the accelerator complex that recently ended.

When the commissioning of the accelerator complex is completed, it should produce approximately twice the intensity of the neutrino beam for use by NOvA, the long baseline neutrino experiment with a 14,000 ton detector at Ash River Minnesota, MINOS+ and MINERvA and approximately twice the intensity of the neutrino beam for MicroBooNE, which will apply liquid-argon TPC technology to the physics of low energy neutrinos formerly studied by MiniBooNE. MicroBooNE will seek to both settle the issue of sterile neutrinos and study the ability of liquid-argon TPCs to measure neutrinos.

Two additional experiments will join the suite of NOvA, MINOS+, MINERvA and MicroBooNE in several years. They are

1. The Muon g-2 Experiment is planned to measure the anomalous magnetic moment of the muon in order to search for new physics. It is based on the earlier BNL experiment that produced a result ~3.6 σ from the standard model prediction. This experiment received CD-1 approval in November 2013, and is scheduled to take data from ~2016-2018.
2. The muon-to-electron conversion experiment (Mu2e) which is designed to be 10^4 times more sensitive than past experiments. This experiment received CD-1 approval in July 2012, and is scheduled to run from ~2019-2022.

These two experiments share some common needs and have led to the creation of a Muon Campus on the Fermilab site to house both of them and to exploit and develop their synergies.

The key to Fermilab's long-term future is the Long Baseline Neutrino Experiment (LBNE), which could be operating in the mid 2020's. The original cost estimates for the project approached 2 billion dollars and would have required over ten years of planning and construction. The project was reconfigured during the summer of 2012 in response to a charge from the Office of Science of the DOE. In the first stage, the accelerator complex would be upgraded to provide a beam to the Homestake Mine in Lead, South Dakota, where a 10 kiloton liquid argon detector would be constructed on the surface. The experiment would measure the mass hierarchy of the three neutrinos and determine its character, "inverted" or "normal", to ~3 σ and it would hunt for CP violation in the neutrino sector at a similar degree of accuracy. LBNE passed its CD-1 review, with a total project cost of $867 million, in December 2012. The lab has expressed the hope that international collaborators might contribute to the project so that a near detector could be built, the far detector could be enlarged to 35 kiloton and could be placed underground in the Sanford Underground Research Facility (SURF) at Homestake, ND. Then LBNE's physics reach would include proton decay and supernova neutrino searches, as in the original plans for the project. International contributions and collaborations are also being sought to achieve these ends.

Until recently Project X was considered another crucial part of Fermilab's long-term plan. Project X aimed to build out the accelerator complex so that it could simultaneously deliver high-intensity proton beams with different beam structures to multiple experimental areas. One goal of Project X was to deliver 5 MW of protons from the accelerator complex, which would be a seven fold increase over the 700KW that the PIP can generate. Due to cost considerations and several technical challenges, the new Fermilab management has proposed that Project X be replaced by more modest and attainable goals. These plans were presented at the review and are still under development, but in all scenarios the goal of 5 MW has been replaced by ~1.2 MW which can be accomplished with present state-of-the-art targetry.

The Fermilab S&T Review took place on site from November 5 through November 7. The review consisted of one day of plenary talks, a second day of breakout presentations and a half day of questions and answers with Fermilab management, closeout preparation by the review panel and closeout with lab management. The appendices to this report provide additional detailed material relating to the review: Appendix A contains the charge letter to Fermilab management, Appendix B lists the reviewers and DOE participants, and Appendix C contains the agenda and links to the talks. The remaining sections of this report detail the findings, comments, and recommendations of the review committee for each of the charge elements that Fermilab was asked to address.

Accelerator Operations

Findings

During the recent 18 month shutdown, the accelerator complex has been refurbished and reconfigured. This was accomplished with an excellent safety record. New ion sources and RFQ were successfully commissioned in the linac. Nine RF cavities in the booster have been refurbished. The recycler has been converted to a proton accumulator and is currently being commissioned. A 300 kW proton beam was re-established in the main injector. Approximately 500 kW beam power is expected in FY 2014.

Progress on the Proton Improvement Plan (PIP) was presented, which appears to be on track. The primary source of the improved performance is the increase in repetition rate of the Booster from 7.5 to 15 Hz (max.) requiring an overhaul of the 19 RF cavities in the ring. In addition, a significant reduction in beam loss is expected from recently completed improvements in the chopping-beam system. Eventually the installation of a chopper in the injection system will reduce losses even more.

Fermilab proposes FY 2014 performance metrics of 3.2×10^{20} protons delivered to NuMI, and 1.2×10^{19} protons delivered to MicroBooNE.

Comments

The proton improvements laid a solid foundation to double the beam power to 700 kW for the upcoming neutrino experiments: NOvA and MicroBooNE. However, with rather limited upgrades of accelerator components, the goal of doubling the beam power may take more time and effort to achieve. An alternative approach, such as an increase in the intensity of individual bunches rather than increasing the repetition rate could be investigated as a backup solution.

Recommendations

None

Test Beam Operations

Findings

Fermilab operates one of two high-energy hadron test beams in the world—the other one is at CERN. Test beams have seen a steady increase in scheduled beam time. The facility is expected to reach saturation in the near future.

The facility has been improved during the past year with enhanced support, more and better instrumentation, and a new high rate tracking area.

Detailed statistics indicating the efficiency of the operation (e.g. time with beam vs total time; degree of meeting the objective of a run, fraction of time with usable beam, etc.) were not available.

The lab is creating a Test Beam Advisory Committee in order to prioritize test beam allocations.

Comments

Test Beam management should develop a set of performance and efficiency monitoring metrics. This will aid in improving the efficiency and throughput of the facility to serve as many beam time requests as possible.

While instituting an evaluation panel is a prudent measure to ensure the quality of the proposals, the lab should make an effort to improve operational efficiency in order to maximize the amount of beam-time requests that can be served. This can take the form of improving the ratio of setup time versus time that data is taken and used. Also, stronger follow-up with the experiments in order to monitor both delivery as well as experimenter's efficiency should help in increasing the overall throughput of the facility.

Recommendations

None

Future Accelerators/SRF

Findings

SRF activities at Fermilab have a broad and well-balanced mix of fundamental surface science, technology development, and engineering, but SRF-related staff has been declining for several years, principally due to the ramping-down of ILC-related R&D in the US.

The SRF program has the goal of supporting Fermilab's high intensity program and develops SRF infrastructure and technology that can be applied to other Office of Science projects. It is coupled to efforts at other national (ANL, TJNAF, SLAC, Cornell) and international institutions (India, DESY, KEK, INFN).

Fermilab has been asked and has agreed to be a major contributor to LCLS-II by supplying superconducting RF and cryogenic equipment, covering about 15% of the total project cost of approximately $1 billion.

The drivers of the Fermilab SRF program have been the ILC and an 8 GeV proton linac referred to as Project X. A comprehensive reference design report for Project-X has been completed.

In light of the large cost and technical challenges for Project-X, the new lab management has decided to proceed first with a smaller upgrade of the existing linac to supply a beam with 1.2 MW to LBNE. Two main options for the linac upgrade were discussed: a new superconducting 800 MeV linac, and an addition to the existing linac that accelerates the beam from 400 to 800 MeV.

A front end demonstrator for Project-X (PXIE) including H- source, LEBT, RFQ, chopper, MEBT, and two types of superconducting RF cavities (HWR and SSR1) is planned. A shielded enclosure is under construction, and the source installed. Other components are being fabricated. Beam from the ion source has been demonstrated in FY 2014, plans call for beam through the RFQ in FY 2015, and full beam in FY 2018.

Project X has published a Conceptual Design Report that is well developed and meets the original goals. The role of an SRF-based proton accelerator and its implementation strategy at Fermilab should be revisited in light of shifting priorities and funding requirements. Included in this, is the reevaluation of PXIE.

Comments

The lab is considering the construction of an SRF linac to increase the booster injection energy in order to obtain the goal of ~1.2MW proton beam power on target. However, one might design the MW accelerator as a small duty cycle machine in order to limit initial costs while maintaining the upgradability to cw operation if/when additional funds become available. Alternately, an increase in injection energy could be provided with room temperature (Cu) technology.

This "afterburner" approach should be much cheaper than the 800 MeV/c linac plan, since it could work with 2 RF cavities versus 6 for the 800 MeV design. On the downside, extant accelerators would have to be moved. There are many options to consider and the lab should study them systematically.

While most of PXIE would be directly applicable to the new 800 MeV linac, a main objective of that project was the demonstration of bunch-by-bunch chopping with a travelling wave kicker. It is not clear that it would have a direct impact on the new priorities of the lab, so a review of the objectives of PXIE is appropriate.

The decision between the least costly linac upgrade ("afterburner") and the full replacement of the existing linac with a superconducting one has wide-ranging implications for ongoing R&D as well as the long-term future of the accelerator complex. A full replacement of the existing linac needs PIXE R&D, and is more likely to attract contributions from India. The reviewers were also told that CERN is likely to contribute in some form to the linac upgrade. However, if the "afterburner" option were chosen, the PXIE R&D work would not be needed for a long time, and these resources could be redirected. Nonetheless, the "afterburner" is not easily upgradable and may be a short-sighted option.

Given the much larger long-term potential of the full replacement it would be interesting to find out what the real minimum replacement machine is to still give 1.2 MW beam power while taking advantage of all possible cost savings (including minimum beam energy, number of cavity types, real estate, technical infrastructure, international collaborations, etc.).

The lab's SRF efforts are substantial and broad ranging from low beta quarter wave and half wave resonators to high beta elliptical structures with diverse applications like the SLAC FEL LCLS-II, ILC, and Fermilab SRF proton acceleration strategies. As a consequence, the SRF efforts could lose focus unless there is a continued evaluation of priorities as decisions are made and other boundaries become more apparent.

LCLS-II presents a large, challenging opportunity which would be a very large perturbation on Fermilab's accelerator division and would have major ramifications in the other activities in which it could be involved. LCLS-II would make large demands on personnel and facilities.

Fermilab should take steps to manage the possible conflicts with other projects that may arise from its involvement in LCLS-II. Some of these projects are internal (Mega-Watt power for neutrino beams) while others involve external institutions like CERN. In particular, Fermilab should develop a staffing and facilities plan with flexible options to respond quickly to a rapidly changing environment.

The decline of the SRF-related staff that has taken place over the last few years at Fermilab will need to be reversed, should LCLS-II activities expand. However, these probably require more engineering and production expertise than the scientific expertise that was required by the ILC, so there should a periodic review of the appropriate mix of personnel in light of continuously changing priorities and limited funding.

Recommendations

1. **The panel recommended that the lab should develop a systematic comparison of the two or more linac upgrade options to reach the MW power goal.** The plan should address what R&D is needed and when, the cost, the role of international contributions, any necessary

infrastructure additions or upgrades, and the upgrade potential of the design. They should determine the implications for the ongoing PXIE and SRF work.

Scientific Computing

Findings

Fermilab operates 3 large, world-class computing centers (FCC, LCC, GCC), serving 4200 scientists. The three computing centers contain 60k cores, 400 PB storage capacity in tapes, 30 PB in disks, and 32k network ports.

The Scientific Computing Division supports community codes and utilities such as ROOT, GEANT4, and Scientific Linux . They also develop codes and tools such as the Art Framework and are developing a FIFE (Fabric for Frontier Experiments) environment to coordinate software projects across experimental projects.

Comments

Fermilab's three centers are well run, with good availability and uptimes and are upgrading in response to expressed scientific requirements within the constraints of realistic budgets. However, no quantitative metrics of facility operations were presented at the review, which makes evaluation of "effectiveness and efficiency of facility operations" difficult.

Supporting the intensity frontier is becoming the highest priority for the computing division. Currently, intensity frontier experimental groups are small compared to CMS. The issue is how to efficiently support their diverse needs. The emphasis has been placed on their commonality and sharing resources. The next step should be providing enough flexibility in the infrastructure and service to satisfy their ever increasing needs. This effort will help to build up a larger neutrino community. The establishment of the Computing Portfolio Management meetings, Scientific Technical Architecture group, and identification of liaisons with intensity frontier experiments are excellent steps that Fermilab has already taken. But more needs to be done. Substantive concerns expressed by members of the HEP community who are not solely reliant upon Fermilab computing are not being dealt with effectively, and need to be sought out and addressed to ensure inclusion of the entire IF community in the conversation. Fermilab should seek resources and explicit partnerships from collaborating National Laboratories and Universities, especially where general and tested solutions exist and can be adopted.

Capacity and capability of accelerator modeling should be directed to the proton improvement project so that the beam power can be continuously increased. The focus should be placed on the physics limits such as the space-charge and the transition in the booster. A mitigation plan for these limits should be developed as a part of hardware improvements.

Accelerator R&D programs seem to be making much more use of CERN (eg. MADX) accelerator simulation packages than of Fermilab driven efforts (eg. COMPASS). Fermilab should investigate the root cause of this shortfall.

For the next S&T Review, Fermilab should prepare and present quantitative metrics for the performance of and user experience with the FCC, GCC, and LCC that include, but are not restricted to: Uptime, Occupancy, Number of unplanned outages, Mean time between outages, Mean time to recovery, number of Trouble tickets fielded, Mean time to resolution, Categories of tickets.

Recommendations

1. **The reviewers request the Scientific Computing Division to develop a plan for supporting software and computing needs for the neutrino experiments which will fully engage and leverage other DOE national labs' expertise and resources.** The plan must enable distributed simulations, data management, and analysis and should include a set of metrics to gauge the success of the plan based on user experiences, both on and off site. The plan should call out any re-prioritization and re-allocation of resources in the Scientific Computing Division needed to align the computing support manpower with Fermilab priorities, as is being done in the accelerator, detector, and research areas.

Tevatron Experiments

Findings

The Tevatron program (CDF and D-Zero) profile was presented in Stuart Henderson's talk. It showed that Fermilab will complete all its high priority analyses by the end of FY 2014.

Ray Culbertson reported on the Tevatron experimental operations activities, which now support the analysis of the Tevatron data.

Tevatron highlights from this year include: a final Higgs result from 166 channels combined from CDF and D-Zero; a 0.5% top mass measurement; s-channel measurements of single top; the di-muon charge asymmetry measurement at the 3.6σ level; QCD soft physics measurements.

The Tevatron expects to publish 70 papers in CY 2013, with an expectation of ~100 from this point on and possibly extending beyond FY 2014. There are still analyses that could be done after FY 2014 if funding permits.

The Fermilab group has made leading contributions to the Tevatron analyses.

Support for visitors to handle management roles and conduct targeted legacy analyses continues to be important.

A plan for data preservation is being implemented by continually moving data to the latest tape technology.

The Tevatron experiments will retain full data analysis capability until 2020 with 2 FTE support for the Data Preservation project from the Scientific Computing Division.

Comments

The collaborations and the lab are to be congratulated for a very successful Tevatron program.

The collaborations have more analysis topics than they can address and are expecting to publish 40-50 publications in FY 2014, which is similar to FY 2013 during which Tevatron papers accounted for 20% of the publications of the lab. Given the manpower shortfall, the focus on high priority analyses is critical – it is important that the unique analyses are completed.

The laboratory computing support for the analyses appears to be commensurate with the needs.

The plan for data preservation via continual data replication is critical and will likely require lab support to maintain through FY 2020. Long-term curation of Tevatron data and the associated software, etc is a challenge that will need to be addressed soon. The lab did not present details about how that will be done.

Recommendations

None

CMS – LHC Physics Center (LPC)

Findings

The CMS program was presented in Stuart Henderson's talk. The program has 3 stages: a. The 7/8 TeV run completed on February 14, 2013 with data analysis scheduled through FY 2017, b. the 14 TeV operations take place from FY 2015-FY 2018 with data analysis through FY 2021, and c. the 14 TeV high luminosity operations start in FY 2019. Richard Cavanaugh presented the CMS report on science analysis and user support.

Fermilab facilitates participation in CMS in a several ways. They provide access to resources such as the Tier 1 center and analysis clusters, the silicon SiDet facility, and test beams. They provide access to CMS operations and construction projects such as the silicon tracker, trigger, HCAL, remote operations center, software and computing activities. They also provide user support through the LHC Physics Center and serve the larger intellectual community with office space.

The CMS-LPC user community consists of about 60 Fermilab scientists and postdocs. There are ~700 active users of the analysis computing facility. In addition, there are nearly 370 visitors and residents at the LPC of which about 50-100 are in residence at any one time.

The LPC has had strong impact on CMS physics output. More than 50% of all the 255 CMS papers have had contributions from the CMS LPC user community, with some key analyses initiated and led by U.S. physicists. Several Snowmass studies were led by participants in the LPC.

Comments

CMS is coming off a spectacular couple of years, and U.S. CMS has been critical to that success and is a key element of the lab program. It was noted that 27% of the FY 2013 lab publications are from CMS. U.S. CMS personnel hold significant leadership positions in CMS thanks in part to the Fermilab facilities.

The facilities for users at Fermilab are excellent with a Remote Operations Center (ROC), the LPC, detector construction facilities and a Tier 1 computing center.

The estimate of ~50-100 users simultaneously at Fermilab participating in the LPC indicates a successful program. There are ~50 users present long term. However, it was hard to assess the cost-effectiveness of the LPC since no metrics were presented.

The lab provides significant support to U.S. CMS, beyond the DOE/NSF U.S. CMS Operations and Construction funding: ~$800k support for LPC; power, cooling and space for computing; detector facilities such as SiDet and good access to technical personnel in electronics development and silicon manpower.

During Q&A, the presenters indicated that they were satisfied with the current level of lab support for CMS.

Recommendations

None

Muon Experiments

Findings

The muon g-2 experiment aims to improve upon the BNL E-821 measurement by a factor of four (to ±0.14 ppm). The improvement will come mostly from a factor of about 20 higher statistics made possible with the Fermilab accelerator complex. This experiment has a strong collaboration consisting of both young physicists and a contingent of experienced physicists who were part of the BNL experiment.

The magnet was moved to Fermilab in a highly publicized series of events during the summer.

Mu2e is an extremely ambitious experiment that endeavors to reduce the sensitivity to muon-to-electron conversion on a nucleus to the 10^{-17} level, about four orders of magnitude better than any previous experiment. It will employ an approach (initially proposed by Lobashev and developed for the ill-fated MECO experiment at BNL) that has not been used in prior experiments. It uses a pulsed beam and series of superconducting solenoids with non-uniform magnetic fields to capture the pions produced in the target, to transport the resulting decay muons to the stopping target, to capture the electrons from muon decay, and then to measure their momenta.

The entire experimental volume is in vacuum. The experiment poses serious technical challenges on several fronts. In addition to detector challenges, the experiment hinges on achieving beam extinction between bunches at the 10^{-9} level.

An improvement of four orders of magnitude in a single experimental step is virtually unknown in the history of particle physics.

The experiment's cost is now estimated at around $250M, almost double the amount that was projected at the time of its initial approval.

A Muon Campus is being constructed to accommodate the g-2 and Mu2e experiments using the 8 GeV proton beam from the booster. The muon campus is created with four AIPs and three GPPs, with the goal of being ready for beam in the third quarter of FY 2017.

Comments

The g-2 and Mu2e experiments constitute a well-defined program and could have unique physics impact if successful. These two groups gave the best presentations in the review: informative, accurate, with a strong and well-thought out physics case together with a detailed overview of the main technical issues and how they would be addressed.

The g-2 experiment is difficult, but the collaboration has a good grasp of the challenges. The critical aspects of the experiment are: 1. shimming the magnet, and 2. measuring the field with sufficient precision.

The Muon Campus is a good approach taking advantage of the common and synergistic requirements of Mu2e and Muon g-2 and takes good advantage of AIP and GPP funding opportunities.

Fermilab and the DOE need to understand the difficulty of the Mu2e experiment and to organize their oversight accordingly. While the Lehman review process is necessary to address issues of project management and costing, it is not sufficient because it is not set up to analyze the complex experimental issues Mu2e confronts. Also, the Fermilab PAC is a broad committee which will not have the needed expertise to provide useful oversight. Therefore, Fermilab should consider forming a standing technical review committee. It should be a standing committee so that topics can be dealt with in depth over time by a group of experts who know the issues, rather than trying to bring a new group of reviewers up to speed every few months. Even a well-chosen committee will need to learn a lot, and a one-shot three-day meeting won't accomplish that.

The standing committee should meet with the collaboration at least twice per year and go into issues in depth. The members should have relevant technical expertise, at least a few of them should be veterans of successful "rare process" experiments, and most should come from outside Fermilab. If done properly, this will be a constructive process, helpful to the collaboration and more likely to find problems than the standard suite of reviews.

Recommendations

None

Neutrino Program

Findings

MINERvA's purpose is to measure neutrino cross sections on a variety of nuclear targets. These will be useful measurements for other experiments. Minerva would like to run with a liquid deuterium target.

MicroBooNE is intended to operate in the Booster neutrino beam to follow up on a low-energy anomaly in the data from MiniBooNE. It will use a liquid-argon TPC, making it also highly relevant as detector R&D for the lab's long-term future. The MicroBooNE experiment is 91% complete and is expected to be finished at least a year before its CD-4 milestone of September of FY 2015.

The NOvA experiment has faced many challenges, but it appears to be on track toward detector completion in 2014. The NOvA experiment is also 91% complete with CD-4 planned in the first quarter of FY 2015. An enormous facility has been built at Ash River, and far-detector installation is far along. Near-detector construction is progressing at Fermilab. In the last year the collaboration discovered a problem with APD noise, which has been attributed to the parylene coating. Commissioning of the completed section of the far-detector is underway.

LBNE is planned to begin operations in 2026. The budget that Fermilab management is working to is $867 million of DOE contributions. With a total cost of $1.2 billion this requires $350-400M in foreign contributions. The plan shown to make this happen has U.S. institutions building the beamline and 5 kilotons of the far detector, and international partners building the near detector and 30 kilotons of the far detector. The accelerator complex will be upgraded, perhaps with an 800 MeV pulsed superconducting RF linac, to allow greater than 1 megawatt on target.

Comments

A deuterium target would tremendously expand the physics utility of the Minerva experiment. The last such target built by Fermilab was used for experiment E-705. The target exploded twice. An extensive safety review would be necessary before Minerva could employ a deuterium target.

The variety of neutrino physics experiments hosted at the lab range from small to large scale (from MicroBooNE to LBNE) allows for the incremental development of techniques and ideas within a reasonable budget. However, the synergy between the various experiments was not emphasized during the review presentations.

While the potential in principle of liquid argon TPCs is clear, much remains to be demonstrated in practice. The crucial technical challenge of the MicroBooNE experiment is the ability to drift electrons over 2.5 m distance. That has not been done before and relies on control of the drift field. That is clearly a key question since the MicroBooNE TPC will be scaled up by a factor of ~200 to meet the plans of the full scale LBNE experiment.

MicroBooNE has an energetic collaboration behind it, but it also faces a challenging task. It is not clear that the collaboration has the depth of experience and the technical expertise to quickly commission a liquid-argon TPC. It may be that the timescale for turning this into an operating detector in a running experiment is being significantly underestimated. In any case, it will be a useful experience for Fermilab, and that experience may help Fermilab and the DOE calibrate the magnitude of the LBNE challenge. The LBNE collaboration has a critical need for additional funding, in particular from international sources, and considerable work is required to establish a management structure that recognizes that need — there are many details that need to be worked out for these substantial partners. They will be involved in the decision making process and the range of their responsibilities and influence will have to be determined.

LBNE should develop such an international management structure as soon as possible. It will have to address the founding of finance boards, establish common costs, etc.

Some of the topics LBNE is designed to address, such as the mass hierarchy, may be settled before LBNE can come online. LBNE is very expensive so its approval may severely limit the opportunities that the U.S. HEP program can address. It also hinges on large international contributions that may be unrealistic.

The assertion that LBNE will engage a collaboration of 1000 physicists seems overestimated; LBNE will require an enormous work force, but a small fraction of that number will be physicists.

LBNE depends on a bold extrapolation of liquid argon TPC technology. The potential for technical setbacks and for significant delays mean that the projected timeline for LBNE involves a leap of faith.

The neutrino physics program at Fermilab needs more coordination and planning between its many parts. The physics case has not been presented in a compelling fashion. The synergy between the various experiments has not been demonstrated. A clear neutrino-experiment timeline needs to be in place which is based on science and technology goals. The program must determine and measure the geometry of the neutrino (and charged-lepton) unitarity triangle, as was done for quarks.

It is important to motivate and develop the neutrino physics program more and reach a more quantitative level that defines the level of accuracy needed to be sensitive to different kinds of new physics, the complementarity with experiments around the world, the possibility of responding to new findings (e.g. from the LHC). This kind of planning can make neutrino physics at Fermilab much stronger and assure the future leadership the lab is aiming for.

Recommendations

1. **The review panel recommended that the lab formulate a coherent plan for its small and mid-scale neutrino experiments, which should include a timeline for physics and technical milestones.** The reviewers did not find the suite of neutrino experiments to be adequately coordinated into a program that had decisive physics goals that lend support to the lab's flagship experiment, the Long Baseline Neutrino Experiment (LBNE).

Strategic Planning

Findings

The director is attempting to fit a large potential program into a constrained realistic budget and timeline. It consists of a full scope LBNE with an underground detector and ~1.2 MW of beam power. As a result, Project-X has been reduced to its minimum: a linac with an 800 MeV proton beam.

A strategy is being developed to solicit international funding up to several hundred million dollars that is necessary to build the full scope LBNE. An international collaboration of ILC may be a part of a negotiated solution.

The strategy of the Illinois Accelerator Research Center (IARC) is being refined, aiming it as a launching platform for new startups utilizing particle accelerator technology. An LDRD program will be initiated to partially seed innovations. One of the stated goals is to emphasize a new business culture at Fermilab and encourage entrepreneurial activities.

Comments

Seeking a large amount of international funding for the full scope LBNE and the accelerator complex is a worthwhile endeavor. However, the success rate of this approach to similar past challenges in the field has been rather low. It is therefore prudent to develop a scheme to continually improve the existing accelerator complex until ~1.2 MW beam power is reached without any international funding.

The stated goal for the Fermilab LDRD program is quite different from those at other laboratories and managing the separation between business activities and academic/research activities and culture may be a challenge.

De-emphasizing or eliminating the academic/research component from IARC could also make it less attractive to the broader scientific community and reduce the level of participation of universities whose students and post-docs could have made good use of that facility.

While Fermilab should make plans that are realistic within foreseeable future budgets, it is not clear that narrowing Fermilab's focus to only neutrinos is in the long-term best interest of U.S. HEP. In the last couple of years, considerable effort has gone into documenting IF physics opportunities. There was a DOE-sponsored IF workshop attended by 500 physicists in December 2011, and then there was Snowmass where a broad IF program was discussed alongside the Energy and Cosmic Frontiers. Neutrinos comprised a major element of the IF program, but by headcount it accounted for less than half the IF participants. If the IF had been defined as neutrinos-only from the beginning, it would have fared less well in the Snowmass process.

It may be a good idea to produce, and refresh whenever necessary, a Fermilab road map that stipulates laboratory priorities, including physics programs pursued and the necessary infrastructure required. Companion road maps for subgroups such as SRF, should also be developed to broadly communicate plans and to guide research, operations, and project activities.

Recommendations

None

Management

Findings

The new Director started in his position in September 2013 and is in the process of putting his management team together. He has taken a series of actions to develop his own strategic plan for the laboratory:

- initiated the first series of all-scientist strategic retreats in Fermilab's history to discuss its future,
- appointed a committee of 28 to prepare for the P5 process and the visit of the committee to the laboratory,
- revived a standing advisory committee that had lapsed many years ago.

This comes at the same time that the HEPAP subpanel, Particle Physics Project Prioritization Panel (P5), is preparing a new strategic plan for the field. Fermilab management will need to both provide input to P5 and respond to their recommendations as part of their strategic planning.

Fermilab is going through a transition period with many recent changes (new director, P5 process underway, negotiations with international partners, etc). The new director plans to narrow the focus of Fermilab to emphasize neutrino experiments and to limit the upgrades of the accelerator complex to technically and financially attainable goals. Many of the director's new plans were presented for the first time at this review.

Fermilab has a budget of approximately $400M/year and about 1700 employees. The lab is leading a suite of experimental projects that range from small endeavors to the largest in the field.

Comments

Given the challenges ahead, it is important that the Director find a Deputy Director that can complement his strengths.

There were instances at the review where the presentations by management, experiment leaders/staff, and P5 presenters differed, so in these times of rapid change it is critical to maintain strong communication channels at all levels so that a coherent and consistent picture emerges both inside and outside the lab.

The director's reestablishment of a weekly scientific committee is commendable.

There is still a critical need for a "PAC like" group to offer external advice on lab program priorities.

As the focus of the lab shifts to the neutrino program, the lab should monitor its publication rate and thesis productivity. In FY 2013 only 3% of the Lab publications were attributed to the intensity frontier. The scientific output of the energy frontier, Tevatron and CMS now, and CMS in the future, will likely continue to be the largest component of publications well into the future and therefore the energy frontier remains an important part of Fermilab's total portfolio.

The quality of the laboratory response to the issues raised by last year's S&T review was disappointing. Many important issues that were raised in the report were ignored or glossed over. Some important issues that were raised in the Executive Summary included: Fermilab's competitiveness internationally; Fermilab’s relationship with the U.S. community; and simulation support for the intensity frontier program. There were many more detailed issues raised as well, but no comprehensive effort to address each one. The reviewers encourage Fermilab to be more responsive in the future.

Recommendations

None

APPENDIX A

Charge Letter to Fermilab Management

Dr. Nigel Lockyer

Director

Fermi National Accelerator Laboratory

P.O. Box 500

Batavia, Illinois 60510

Dear Dr. Lockyer:

The Office of High Energy Physics will conduct a Science & Technology (S&T) Review of the laboratory's scientific user facilities. The review will be held at the laboratory, November 5–7, 2013. The goal of the review is to assess the current performance of the facility, the science resulting from the experiments that are served by the facility, and plans for future improvements to the facility, where the facility is the Accelerator Complex which consists of the Main Injector, Booster and Linac, the NuMI beam, and all other beams provided to experiments. For this review the panel will also be asked to include its assessment of the facilities that Fermilab provides to support the needs of the US CMS user community. As part of this review, the laboratory should present its proposed performance metrics for NuMI in FY 2013 and FY 2014.

In particular, each panel member will be asked to evaluate and comment on:

- The quality and significance of the laboratory's recent scientific and technical accomplishments; and the merit, feasibility and projected impact of its future planned physics program;
- The effectiveness and efficiency of facility operations, and the planning for future facility upgrades to support the research program including appropriateness of the proposed performance metrics in terms of being realistic and maximizing the scientific productivity of the facility;
- The effectiveness of laboratory management in strategic planning, developing appropriate core competencies, implementing a prioritized and optimized program, and promoting and implementing a safe work environment;
- The leadership, creativity, and productivity of the facility's scientific and technical staff in carrying out the above activities; and
- The quality and appropriateness of the laboratory's interactions with, and nurturing of its scientific community.

In addition, the review committee will be asked to assess Fermilab's progress toward becoming the premier intensity frontier laboratory in the world, the coherence of the Fermilab intensity frontier program and the planning and computer support for the various intensity frontier experimental initiatives at the lab.

The first and second day will consist of presentations by the laboratory and executive sessions. The third day will be used for an executive session and preliminary report writing; a brief close- out will take place in the late afternoon. Preliminary findings, comments and recommendation will be presented at the close-out.

Dr. John Kogut will chair the review and serve as our contact on all aspects of the review. He can be reached at (301) 903-1298 or John.Kogut@science.doe.gov . Materials for the review committee should be supplied via a website at least two weeks before the review.

Each panel member is being asked to review all aspects of the program based on the Accelerator Complex. In addition, each panel member will be asked to evaluate in greater detail those parts of the program in which they have specialized expertise. They will be asked to write individual letters on their findings. The Chairman will accumulate these letters, and compose a DOE report based on the information in the letters. In addition, copies of the letters with identifying information removed will be included with the report.

I greatly appreciate your efforts in preparing to present your laboratory's activities before this annual review. It is an important process that allows our office to understand the accomplishments, quality, needs, and plans of Fermilab. I look forward to a very informative and stimulating visit.

Sincerely,

James Siegrist

Associate Director of Science for High Energy Physics

Enclosure

cc: Michael Procario, SC-25.2

Glen Crawford, SC-25.1

Michael Weiss, FSO

APPENDIX B

Reviewers for FermiLab S&T Review, Nov 5-7, 2013

1. **ColliderPhysics/Detector Ops (2)**

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2. **Neutrinos and Fixed Target Experiments (2)**

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3. **Strategic Planning (2)**

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4. **Accelerator Ops (2)**

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6. **Phenomenology/BSM (1)**

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7. **Future Detector/Mu2e/g-2/MicroBooNE (2)**

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8. **Computing Support (1)**

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APPENDIX C

Fermilab 2013 S&T Review Link and Agenda

https://indico.Fermilab.gov/conferenceDisplay.py?confId=6589

2013 Fermilab Annual Science and Technology Review - November 5-7, 2013

Meeting rooms

Comitium for Executive / Closed Sessions, Plenary Sessions & Closeout

Black hole (accelerators) & Snake pit (experiments: detectors & computing) for Parallel Sessions

Tuesday, November 5, 2013 (Plenary) Comitium (WH2SE)

Chaired by John Kogut (DOE) and Peter Wilson (Fermilab)

8:30 am Executive Session

9:00 am – 2:45 pm Plenary Presentations Time	Topic	Speaker	Presentation / Discussion
8:30 am		Executive Session	
9:00 am	Laboratory News and Strategy Plan	S. Henderson	25' + 10'
9:35 am	Response to 2012 Comments and Recommendations	G. Bock	15' + 10'
10:00 am		Coffee Break - Comitium Alcove	
10:30 am	Accelerator Complex: Performance and Plans	Paul Derwent	25' + 10'
11:05 am	Detectors: Performance and Plans	Mike Lindgren	25' + 10'

11:40 am	Scientific Computing: Performance and Plans	Rob Roser	25’ + 10’
12:15 pm		Lunch - Wilson Hall 2nd Floor Crossover	
1:15 pm	intensity frontier Program	Steve Brice	30’ + 15’
2:00 pm	Long Baseline Neutrino Experiment Project	Jim Strait	30’ + 15’
2:45 pm		Coffee Break - Comitium Alcove	

Breakout 2a. Experiment: Science Analysis and User Support

Snake Pit (WH2NE)

Co-chaired by Tim Bolton (DOE) and Mike Lindgren (Fermilab)

3:10 pm	NOvA Transition to Operation	Richard Tesarek	10’+5’
3:25 pm	MINOS +	Rob Plunkett	15’+10’
3:50 pm	MINERvA	Debbie Harris	15’+10’
4:15 pm	CMS	Rick Cavanaugh	25’+10’
4:50 pm	Tevatron	Ray Culberston	10’+5’

Breakout 2b. Experiment Support Facilities

Black Hole (WH2NW)

Co-chaired by L.K. Len (DOE) and Rob Roser (Fermilab)

3:10 pm	Testbeam: Ops Users and Analyses	David Christian	20’+ 10’
3:40 pm	Detector Development Facilities	Rick Ford	20’+10’

4:10 pm	Computing Support Facilities	Oliver Gutsche	20'+10'

5:05 pm Executive Session - Comitium

6:30 pm Refreshments – Chez Leon

7:00 pm Dinner – Chez Leon

Wednesday, November 6, 2013

8:30 am – 9:40 am Closed Session: Discussion of Management Issues with Directorate

Nigel's Talk + Q&A

9:40 am – 10:00 am Coffee Break - Comitium Alcove 10:00 am – 2:40 pm Parallel Sessions Time	Topic	Speaker	presentation / discussion

Breakout 1: Accelerators: Projects and Technology Development Snake Pit (WH2NE)

Co-chaired by L. K. Len (DOE) and Paul Derwent (Fermilab)

10:00 am	Proton Improvement Plan	Bill Pellico	35' + 15'
10:50 am	Muon Campus	Mary Convery	35' + 15'
11:40 pm		Lunch - Wilson Hall 2nd Floor Crossover	
1:00 pm	Mega-Watt Proton Upgrade	Steve Holmes	20' + 10'
1:30 pm	Project X Injector Experiment	Sergei Nagaitsev	25' + 15'
2:10 pm	Superconducting RF	Vyacheslav Yakovlev	20' + 10'

Breakout 2: Experiments: Projects and Technology Development

Black Hole (WH2NW)

Co-chaired by Tim Bolton (DOE) and Steve Brice (Fermilab)

10:00 am	NOvA Project	John Cooper	25' + 15'
10:40 am	MicroBooNE Project	Gina Rameika	20' + 10'
11:10 am	CMS Upgrade Project	Steve Nahn	20' + 10'
11:40 pm		Lunch - Wilson Hall 2nd Floor Crossover	
1:00 pm	Muon g-2 Project	Chris Polly	20' + 10'
1:30 pm	Mu2e Project	Doug Glenzinski	25' + 15'
2:10 pm	intensity frontier Physics with a Mega-Watt Proton Source	Bob Tschirhart	20' + 10'

2:40 pm Coffee Break - Comitium Alcove

3:20 - 4:20 pm Executive Session - Comitium (WH2SE)

4:20 - 5:20 pm Laboratory Response to Questions - Comitium (WH2SE)

5:20 - 6:00 pm Executive Session - Comitium (WH2SE)

6:00 pm Adjourn

Thursday, November 7, 2013 (Plenary) -Comitium (WH2SE)

8:30 am Closed Session: Laboratory Response to Questions 9:30 am Executive Session (Report Preparation)

12:00 pm Working Lunch

1:00 pm Closeout (Comitium)

2:00 pm Closeout; Chair with Director (Director's Office)