Fermilab Physics Advisory Committee Report, April 2026

The Physics Advisory Committee:

In person: Klaus Blaum (Local Chair), Aida El-Khadra, Joe Formaggio, Elisabetta Gallo, Cecilia Gerber, Stefania Gori, Zach Marshall, Fulvia Pilat, Mayly Sanchez,

Remote: Halina Abramowicz (Chair), Allen Caldwell, Lara Faoro, Sunil Golwala, Deborah Harris, Atsuko Ichikawa, Tim Tait, Brigitte Vachon (ex-officio, DPC Chair)

Scientific Secretary: Sergo Jindariani

Executive Summary

The PAC meeting was in large part dominated by discussions of the lab's prioritization program presented by the lab Director, Norbert Holtcamp. The plan focuses on the successful, on-schedule, and on-budget execution of the LBNF/DUNE project and the PIP-II accelerator upgrade, as well as on successful completion of the HL-LHC upgrade program and the Mu2e project. The plan builds on the DOE directives, budget realities and significant infrastructure needs. The DOE directives were presented by the director of the Office of HEP, Regina Rameika, The main charge of PAC was thus to address the potential scientific loss to the lab given that some projects may need to be delayed or discontinued at FNAL. As a general comment, for any cuts to the research program, the PAC thought it important to consider not only the immediate savings but also the long-term impacts on the lab, which may include broader effects on users and affiliates, as well as the loss of core scientific capabilities needed to support new and ongoing experiments and maintain leadership in the field.

Subject to discussion was the fate of the NOvA experiment with beam time (NuMI) available in FY27 and the SBN experiments (SBND, ICARUS and ANNIE) with beam time (BNB) available in FY27 and in FY28. The PAC concluded that running 12 weeks rather than 20 weeks of both NuMI (as required by DARPA) and BNB in FY27 will not adversely impact neutrino science. At least 12 additional weeks of BNB running in FY28 are recommended. Given the current DUNE schedule, there was no compelling physics case presented for running the SBN program after the long shutdown (LS). Also discussed was the future of the SY120, which will not be operated before the LS due to budget constraints and the long term operation of which would require significant investment. The SY120 provides beam to the Fermilab Test Beam Facility (FTBF) and to the Spinquest/Darkquest experiments. The PAC felt that the lab should develop a

sustainable funding model for preserving the unique capabilities of Irradiation Test Area (ITA) and FTBF in the post-LS era in order to support instrumentation R&D. SpinQuest and DarkQuest provide unique measurements and new particle discovery opportunities, respectively, and are therefore an attractive program to be carried out by FNAL should the SY120 be reactivated. As far as the Cosmic Frontier is concerned, the group has already been proactive in narrowing down the scope of their program by making key strategic decisions regarding which experiments to engage in. They have focused on experiments where Fermilab acts as either the lead lab, or provides unique capabilities not available elsewhere. The PAC believes that this is a good guiding principle and that there may not be much to be gained financially by further cuts.

As usual, the PAC heard a report of the DUNE Program Committee (DPC), a merger in fall of 2025 of the Long-Baseline Neutrino Committee (LBNC) and Neutrino Scope Group (NSG) committees, presented by the chair Brigitte Vachon. The PAC was pleased to hear that the 2026 European Particle Physics Strategy Update calls explicitly for CERN to continue to provide support to the global long-baseline neutrino program via the Neutrino Platform. The DPC chair reported good progress on all fronts of the Far Site. There is substantial progress in the design of all components of the Near Detector complex. However, the Near Site Conventional Facilities (NSCF) and Beamline are on the critical path towards physics with beam. NSCF construction bids, well above cost estimate in April 2025, prompted review of technical, procurement and economic benefit analyses. The DUNE Collaboration and US Project established 10 dedicated NSCF Task Forces and a coordinating Steering Group, charged to evaluate cost-saving options with minimal impact on physics capability and safety. While DUNE is progressing well in all technical aspects and in transitioning into the construction phase with current focus on the FAR Detectors installation and integration planning at SURF, the path forward for Near Site execution remains the highest priority for the stakeholders.

The report on accelerator status was preceded, at the request of PAC, by a report of the Accelerator Advisory Committee (AAC) in the executive session. The AAC's main task is to review status and activities related to the accelerator complex (refurbishment, upgrades, operations), addressing PIP-II, and activities at the unique IOTA / FAST facility. The first of these were reported in detail by Alexander Valishev, the interim ALD for Accelerators. The MI has not operated since July 2024; the rest of the accelerator complex did. The PAC commended the accelerator team for the productive operation of the BNB to date in FY26, which delivered an integrated POT exceeding the base metric by 25%. Three out of eight transformers are currently operational. Three more transformers need to be refurbished after bushings repairs and two new transformers

are being procured. The campaign of maintenance and modernization of the MI is in progress.

The PAC was pleased to hear that a dedicated position has been created, tasked with overall integration and specifically with developing an integrated plan for the delivery of LBNF/DUNE. The initiation and progress of various accelerator AI/ML tools, for instance, tools for MI/Recycler loss disentanglement and Booster tuning, are welcome developments and should be continued, with a focus on deploying AI/ML tools in real operations.

The PAC was also presented with plans of the Microelectronics activities and the developing strategy for the lab's AI/ML efforts. These were discussed in executive sessions, seeking PAC's input for the FNAL vision for supporting the Genesis Platform. In another executive session, the PAC was given a short report on the progress in preparations of the Mu2e experiment with a good prospect for a data taking run before the LS.

Status and plans for the Fermilab's accelerator complex

Charge: We ask the committee to review the status of Fermilab's accelerator complex with particular emphasis on plans for NuMI and SY120 ahead of the Long Shutdown. The committee is also asked to review the status of the recommendations made at previous reviews:

1) Given the recent decline in accelerator reliability, there is an urgent need to modernize the aging systems, particularly in light of the upcoming DUNE project.

   Please provide a status update of the modernization efforts, in particular towards 1.2MW, and taking into account questions/comments made at the last PAC review.
2) The accelerator operations, optimization and monitoring has high potential for modernization by AI. The PAC requests a presentation about on-going and planned work in this area

Findings:

- The MI has not operated since July 2024, while the rest of the accelerator complex has. The FY26 yearly shutdown is planned for June-Sep 2026. A 20 week run is planned from October 2026 to Feb 2027 to run NuMI. The long shutdown is planned for 2028-29.
- The Booster neutrino beam (BNB) ran in FY2025/2026 with an uptime of >90% in Dec 2025 and Jan 2026, and lower availability in February and March 2026. The actual beam, i.e. integrated POT, exceeds the base metric by 25%.

- 3 out of 8 13.8 kV transformers are currently operational. 3 transformer bushings need to be repaired: the last one is expected on July 20. The transformers need then to be refurbished. 2 new transformers (6 M$ each) are being procured.
- There are 2 weeks contingency between the installation of the last transformer and October 1, when it is needed for the NuMi run.
- No switchyard runs are planned given the budget constraints. The long-term switchyard program is currently unfunded.
- A position has been created (B. Zwaska) charged with overall integration and specifically with the creation of an integrated plan for delivery of LBNF/DUNE.
- The campaign of maintenance and modernization of the MI is in progress.
- Several AI/ML applications are being developed to support accelerator operations, including MI/Recycler losses disentanglement, booster tuning and an AI accelerator logbook.

Comments:

- The PAC commends the accelerator team for the productive operation of the BNB to date in FY26.
- The NuMI run in FY2027 has been reduced from 30 weeks to 20 weeks for budgetary reasons. The PAC believes that a further reduction to 12 weeks of NuMI running time will not have a critical impact on the scientific output. However, the MI needs to reestablish reliable operations after the long down time. If restarting operations takes longer than planned or if problems develop during the run, the schedule should remain flexible enough to ensure 12 effective weeks of running.
- FNAL has decided not to run SY120 before the long 2028–29 shutdown for budget reasons. The PAC concurs with the decision but strongly advises FNAL to retain the possibility of running SY120 after the long shutdown.
- The delivery of the last repaired transformer planned for September 15 leaves only 2 weeks before the start of the planned NuMI run: we encourage the lab to prepare contingency plans in case the delivery or repair of the transformers are delayed.
- The PAC supports the creation of a position charged with overall lab integration efforts to deliver beam to LBNF/DUNE, in response to the identified need of coordination among the projects and the programs executing off project scope (PIP-II integration, infrastructure, etc.). It will be imperative for the success of such an endeavor to ensure clear lines of responsibilities and authority for the coordinator.
- The initiation and progress of various accelerator AI/ML tools, for instance tools for MI/Recycler loss disentanglement and Booster tuning, is a welcome

development that should be continued with a focus on deploying AI/ML tools in real operations. Real accelerator applications can be a valid foundation for present and future Genesis proposals based on and strengthening FNAL core competences.
- The IOTA program is an accelerator R&D program supported by GARD, that recently added a proton beam to the electron capabilities. The program is essential in supporting the power increase of the FNAL accelerator complex even if not explicitly part of the stated lab priorities. The Committee would like to hear more at the next meeting about the plans and the overall strategy of the IOTA program in general, and in particular about AI/Genesis opportunities.

Recommendations:

- If the decision is to limit the scheduled run of the NuMI to 12 weeks in FY27, the lab needs to provide enough flexibility in the overall schedule to ensure 12 weeks of effective running.
- The PAC recommends that BNB runs for at least 12 weeks in each of FY27 and FY28.
- The PAC would like to hear more about IOTA strategy and impacts at the next meeting.

Report from Microelectronics

Charge: We ask the PAC to review the status of the MicroElectronics (ME) activities at the laboratory and of the recommendations made at past meetings:

1. The lab should support the ME group in getting access to appropriate tools for ASIC development.
2. The PAC would like to see a prioritized technical portfolio inside the reduced funding scenario.

Findings:

- The microelectronics group grew from 7 to 26 FTE since 2010.
- The majority of the funding comes from the DOE, with modest funding from industry and new department of commerce projects for cryo electronics. Some department of defense funds were also secured.
- The core capability for HEP is smart sensors.
- New capabilities of ASIC Cryogenics and Robotic Testing require infrastructure upgrades that remain unfunded.
- Access to ASIC development tools remains unresolved.

Comments:

- The PAC was not presented with the prioritized technical portfolio inside the reduced funding scenario that had been requested.
- The funding model for the microelectronics group, including the necessary tools for ASIC development, does not appear sustainable.
- A mechanism to hire temporary staff would provide flexibility when priority in funding areas evolves.
- In the future, care should be taken to align applications to funding opportunities with existing infrastructure and laboratory priorities.
- The projects of the microelectronics group should align with the goal of preserving the unique core capabilities required for future HEP projects, including QIS. The plan should include a funding model for the infrastructure needs.

Recommendations:

- Lab management should arrange an external review of the group's alignment with the lab mission and develop a plan for a sustainable funding model.

Status of the Cosmic Frontier program

Charge: We ask the PAC to review the status and strategy of the Cosmic Frontier efforts at the laboratory, taking into account reduced budgets in recent years.

Findings:

- The Cosmic frontier engages in a broad program focused on understanding particle physics through measurements of the cosmos. This leverages Fermilab's long history of large galaxy surveys and growing program in quantum sensing and AI.
- The program incorporates a breadth of different experiments, such as large galaxy surveys (Rubin), CMB, Dark matter including axions (ADMX), and quantum sensing.
- Projects currently highlighted in the presentation (Rubin/LSST, SPT-3G, ADMX-G2, SuperCDMS, etc) are ones in which the lab plays a lead role or delivers key infrastructure to the experiment.
- The group has also been leveraging key, unique lab facilities (QICK, silicon detectors, underground quantum testing facility, etc) to make a strong impact.
- The group has had good success with finding support for existing projects, but had to narrow the scope of their program to align with the DOE priorities. OBSCURA stands as an example with expertise started here but Fermilab no longer playing a lead lab role.

Comments:

- The committee commends the Cosmic group for their success in leveraging Fermilab's strengths and expertise in pushing in this exciting and growing area of particle physics.
- The program has been able to bring in excellent talent into their fold, with strong leadership and visibility in the field.
- *SiDet and NEXUS also stand out as unique Fermilab capabilities that are difficult to find elsewhere in the US.*
- The group has already been proactive in narrowing the scope of their program, in making key strategic decisions of which experiments to engage in. They have highlighted experiments where Fermilab acts as either the lead lab, or provides unique capabilities not available elsewhere. The committee believes this is a good guiding principle.

Recommendations:

- Continue the strategy of focusing on areas where FNAL is a leader of or crucial to DOE Cosmic Frontier projects with an effort made to preserve unique capabilities that have been built up over many years.

Status and Plans of SBND

Charge: We request that the PAC provides feedback on the physics objectives of the SBND experiment for a reduced running scenario before the Long Shutdown, e.g. up to 20 weeks of BNB running in FY27 and plans for FY28 remaining unchanged. We also ask the PAC to comment on whether these plans would be affected if running after the long shutdown were to become an option.

Findings:

- Several scenarios for operation were presented, including an intermediate scenario of 20 weeks in FY27 and 12 weeks in FY28, and a maximal scenario with some 60–70 total additional weeks of running.
- The intermediate scenario results in 50% more POTs than currently collected.
- About 15% of the collected data have been analyzed.
- High-statistics neutrino-nucleus cross section measurements will yield important model constraints in aid of the DUNE physics program. This data set provides significant coverage of the kinematic phase space. This is particularly true for the second oscillation maximum and the critical dip region.

- Reverse horn current operation would provide a very significant anti-neutrino enriched sample on argon. Accomplishing this would require power supply upgrades to BNB horn, estimated at $250K.
- There is a substantial overlap between the SBND collaboration membership and the DUNE collaboration membership.

Comments:

- The PAC commends the SBND collaboration for the successful execution of the experiment and progress on their analysis program.
- The PAC endorses running in FY27 and FY28 with a minimum of 12 weeks in each running period.
- Balancing of FNAL personnel between SBND and DUNE should be considered.
- The reach of the experiment on dark matter appears to be relatively marginal.
- Given the current DUNE schedule, the PAC does not see a compelling science case for post-LS running of SBND.

Recommendations:

- The experiment should begin to negotiate with laboratory management the issue of long-term data preservation for future analyses, even past the active lifetime of the collaboration.
- The PAC recommends that SBND receives at least 12 weeks of BNB running time in each of FY27 and FY28.

Status and Plans of ICARUS

Charge: We request that the PAC provides feedback on the physics objectives of the ICARUS experiment for a reduced running scenario before the Long Shutdown, e.g. up to 20 weeks of BNB and NuMI running in FY27 and plans for FY28 remaining unchanged. We also ask the PAC to comment on whether these plans would be affected if running after the long shutdown were to become an option.

Findings:

- The ICARUS experiment is currently in its Run 5 and has accumulated $9.7 \cdot 10^{20}$ POT from the BNB beam and $6.2 \cdot 10^{20}$ POT from the NuMi beam. Notably, $5.87 \cdot 10^{20}$ BNB POT were in common with the SBND experiment.
- The collaboration has completed several publications on neutrino-argon cross section measurements in the DUNE energy range, and has established new

bounds on the existence of sterile neutrinos. Several more analyses are currently underway.
- Both the BNB and NuMI beams are vital for the ICARUS program. The neutrino energy spectrum from NuMI covers the first oscillation peak with resonance and DIS interactions, which are dominant in DUNE. The BNB beam is utilized to investigate sterile neutrinos by comparing nu_e and nu_μ interactions at different distances from the target, as measured by ICARUS and SBND.
- ICARUS is pursuing searches for dark sector particles, including axion-like-particles and dark Higgses.
- The experiment continues to receive significant support from INFN and the European Commission.
- ICARUS is planning a dedicated study to evaluate the benefits of a possible run following the long shutdown.

Comments:
- The PAC commends the Collaboration for its progress in capitalizing on recent data-taking cycles, which has already resulted in several publications.
- The PAC noted that continuing operations after the long shutdown may conflict with DUNE operations, presenting significant logistical and scheduling challenges.
- The reach of the experiment on dark sector particles decaying into muons appears to be relatively marginal.
- 12 weeks of BNB beam operation in FY27 is important for the experiment and would lead to an increase in statistics of approximately ~25%.
- A compelling science case for post-LS running of ICARUS was not presented to the PAC.

Recommendations:
- The PAC recommends that ICARUS receives at least 12 weeks of BNB running time in each of FY27 and FY28.

Status and Plans of ANNIE

Charge: We request that the PAC reviews the of the ANNIE experiment for a reduced running scenario before the Long Shutdown, e.g. up to 20 weeks of BNB running in FY27 and plans for FY28 remaining unchanged.

Findings:

- The Accelerator Neutrino Nucleus Interaction Experiment (ANNIE) in the Booster Neutrino Beam (BNB) has a double goal: 1) the study of neutrino-water (mainly oxygen) interactions and 2) R&D on new neutrino detection technologies based on liquid scintillator using advanced photosensors.
- ANNIE data analyses include: neutral current (NC) and charged current (CC) cross sections in a kinematic region compatible with DUNE and Hyper-K; neutron multiplicity measurements for CC interactions; joint cross-section analyses on O/Ar with data also from MiniBoone and SBND. These four analyses (4 PhD theses) are in progress and will be published by the end of 2026.
- Since 2023, ANNIE has been running with Large Area Picoseconds PhotoDetectors (LAPPD), establishing sub-nanosecond timing.
- ANNIE is part of the international effort on R&D on hybrid scintillator detectors, aligned with the DRD2 Collaboration at CERN and with the US P5 recommendations. They demonstrated the hybrid technique with Water-based scintillators (WbIS) and Gd-WBLs for neutron detection and aim at demonstrating this technique with larger active volumes in FY27–FY28.

Comments:

- The PAC recognizes the importance of joint analyses of neutrino cross sections with different targets, like Oxygen and Argon, and of measuring neutron multiplicities in CC events. Both are important in tuning neutrino–nucleus interactions models, which are essential to decrease systematic uncertainties for future neutrino experiments.
- ANNIE is unique in the R&D of this type of hybrid scintillators with fast photosensors, which are aimed at next generation large scale neutrino experiments.
- There is considerable support for investment and operation for FY 27/28 from University groups and ANNIE runs parasitically to other experiments, and so the cost for operations to FNAL is minimal.

Recommendations:

- The PAC recommends that ANNIE receives at least 12 weeks of BNB running time in each of FY27 and FY28.

Status and Plans of NOvA

Charge: We request that the PAC review the updated NOvA physics case for running in the period up to the Long Shutdown.

Findings:

- NOvA continues to produce science results using data collected to date, with 6 papers over the last 2 years, and several more either under journal review or in preparation with the collaboration.
- To date, NOvA has the most precise measurement of |Delta m^2_23| of better than 1.5% precision, matched only by their joint analysis with T2K, at similar precision.
- A combination of reduced statistical uncertainty and improvements in systematics uncertainties could lower the total uncertainty to near 1.3%.
- The value measured by NOvA excludes the extremal values of CP violation and mass ordering, although the best value falls at the region of greatest ambiguity between mass ordering and CP violation.
- It is noted that the JUNO experiment is now taking data and could reach 0.5% in two years of data taking in |Dm^2_23|.
- By looking at the tension between reactor data and long baseline measurements, some hints of the mass ordering could be achieved, with studies indicating a combined sensitivity approaching 3-sigma.

Comments:

- The PAC commends the NOvA collaboration for continued success in pushing exciting science results with the data collected over previous years of running.
- The expected improvement in |Dm^2_23| is not significant enough to act as a driver for extended beam running.
- A redirection of FTEs from operations to other tasks should be considered as a possible cost saving measure, if necessary.
- There appears to be no strong physics case for continued collection of data beyond what has been collected to date. Improvements in the analysis and continued work on science papers based on existing data is encouraged, including work on joint analysis with T2K and potentially other experiments.

Recommendations:

- None

Status of the SpinQuest experiment and its dark sector upgrades

Charge: We ask the PAC to review the status of the SpinQuest experiment and its potential upgrades. We also ask the PAC to comment on the physics case if running after the Long Shutdown were to become a possibility.

Findings:

- The SpinQuest program includes both hadronic physics and beyond the Standard Model (BSM) physics
- The hadronic physics program is based on Drell-Yan production to shed light on the proton spin puzzle in a regime that is inaccessible to any other experiment.
- The Collaboration has shown that it successfully reconstructs J/psi events with a good signal to noise ratio.
- The BSM program is based on the production and observation of visibly decaying dark particles which provide a unique window into the nature of dark matter.
- The Collaboration showed that the polarized target can be operated successfully with 90% polarization for spills of 3E12 protons.
- The experiment received ~10^15 POT in the summer of 2024 but has not received a beam since then. The plan of the experiment was to data take in Q4 of 2026, if the switchyard run was not cancelled due to budget reductions.
- The experiment led performance studies of four EMCal modules from the 2024 FNAL test beam for the BSM program. The results have been published in a paper in July 2025.
- The experiment has a four-year data taking plan for post-long-shutdown running.

Comments:

- The PAC commends the Collaboration for its progress and for the outcome of the commissioning run.
- The polarized target developed by the collaboration is unique and allows for important nuclear spin measurements.
- The sensitivity to Dark Photon production would be world-best in significant parts of the allowed coupling vs. mass parameter space until SHiP results are released (~mid of ‘30). The experiment also has discovery reach for many additional dark sector models that cannot be tested at any other experiments in the next approximately 10 years.
- The collaboration is encouraged to investigate alternative locations to carry out their experimental program for the case that the switchyard is not restored.

- SpinQuest and DarkQuest provide unique measurements and new particle discovery opportunities, respectively, and are therefore an attractive program to be carried out by FNAL should the switchyard be reactivated.

Recommendations:

- None

Status and Plans of Fermilab Test Beam Facility (FTBF)

Charge: We request that the PAC provides feedback on the status and plans of FTBF, including plans for after the Long Shutdown

Findings:

- The FermiLab Test Beam Facility (FTBF) has been operating since 2005 with over 1000 users from more than 30 countries.
- The beam is slowly extracted from the main injector (MI) down a beamline referred to as the “switchyard”, yielding 120 GeV protons (MTEST) and secondary pion beams (MCENTER). MTest provides fast turnaround for experiments, detector tests and R&D, 7 experiments can run simultaneously.
- The facility also provides workforce development, theses, LDRD, support for ArCS and EMPHATIC, etc. and has resulted in an average of 5 publications per year.
- Facility improvements were executed and intended for 2026 beam operations.
- FTBF received 7 weeks of beam in FY24, while the FY25 operations were suspended because of transformer problems. 12 weeks of beam were planned for FY27 but have recently also been cancelled due to budget reductions.
- Plans for improvements to FTBF were recently discussed and documented by a Test Beam Task Force; the report was released in November 2025.
- Options for alternative test beam facilities in other locations at the lab would require significant infrastructure changes and beamline work.
- The Irradiation facility continues to operate since it depends on beam from the LINAC. However, it would need to be moved to PIP-II after the shutdown, when the LINAC will be decommissioned.

Comments:

- The FTBF is a unique US facility that provides essential support to the global HEP community.
- The current FTBF and Irradiation Test Area (ITA) facilities are heavily subscribed and have contributed to the R&D success of dozens of experiments including Muon g-2, Mu2e, CMS, ATLAS, EIC, SBND, DUNE and NOvA. Crucial choices on detector technologies for these experiments were taken based on these test beam data.
- The FTBF users include many early career researchers. An average of five publications per year are produced and the work represents a unique experience for students and postdocs to see the full cycle of an experiment.
- Canceling the beam in FY27 affects a broad range of initiatives. The international situation for proton test beams is exacerbated by the fact that the CERN beam will also pause operation in summer 2026.
- Recent surveys of HEP test beam and irradiation needs have made clear that there will continue to be a heavy demand for these capabilities for future instrumentation activities in HEP and beyond.
- Investment is required to maintain these, or equivalent, capabilities at Fermilab for the period after the long shutdown.

Recommendations:

- The PAC recommends the laboratory works with the DOE to develop a sustainable funding model for preserving unique capabilities of ITA and FTBF in support of instrumentation R&D after the long shutdown.