2023 High Energy Physics Advisory Pannel (HEPAP) Facilities Charge

In response to Dr. Berhe's December 2023 Facilities Charge, the High Energy Physics program is providing the following list of projects for consideration by the subcommittee.

Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE)
Total Project Cost (TPC) range: $3,160-3,677M
The Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) Line-Item Construction project is a federal, state, private, and international partnership developing and implementing the technologies of particle accelerators and detectors to enable world-leading research into the fundamental physics of neutrinos, which are the most ubiquitous particles in the universe while at the same time among the most mysterious. Determining relative masses and mass ordering of the three known types of neutrinos will give guidance and constraints to theories beyond the Standard Model of particle physics. The study and observation of the different behavior of neutrinos and antineutrinos will offer insight into the dominance of matter over antimatter in our universe and, therefore, the very structure of our universe.

LBNF/DUNE will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, which are expected to help explain the fundamental physics of neutrinos and the puzzling matter-antimatter asymmetry that enables our existence in a matter-dominated universe. Neutrinos are produced in a high intensity beam at Fermi National Accelerator Laboratory (FNAL) in Batavia, IL and travel to the large underground detectors in South Dakota, 800 miles away.

The LBNF/DUNE project comprises a national flagship particle physics initiative. LBNF/DUNE will be the first-ever large-scale international science facility hosted by the United States. As part of the implementation of the High Energy Physics Advisory Panel (HEPAP)-Particle Physics Project Prioritization Panel (P5) recommendations, the LBNF/DUNE project consists of two multinational collaborative efforts:

- LBNF is responsible for the beamline and other experimental and civil infrastructure at FNAL and at the Sanford Underground Research Facility (SURF) in South Dakota. SURF is currently operated by the South Dakota Science and Technology Authority (SDSTA), a quasi-public agency created by the State of South Dakota and hosts experiments supported by DOE, the National Science Foundation, and major research universities.
- DUNE is an international scientific collaboration responsible for defining the scientific goals and technical requirements for the beam and detectors, as well as the design, fabrication of detector components, and subsequent research program.

The LBNF/DUNE project has been subdivided into five subprojects with nearly independent scope. The subprojects and their most recent Critical Decision (CD) approved dates are:

1. LBNF-DUNE Far Site Conventional Facilities-Excavation – CD-2/3 approved 8/19/2022
2. LBNF-DUNE Far Site Conventional Facilities-Buildings and Site Infrastructure – CD-2/3 approved: 3/25/2023
3. LBNF-DUNE Far Detectors and Cryogenics – CD-3A approved 3/25/2023
4. LBNF-DUNE Near Site Conventional Facilities and Beamline - CD-3A approved on 3/25/2023
5. LBNF-DUNE Near Detector - CD-1RR approved 2/16/2023

Cosmic Microwave Background - Stage 4 (CMB-S4)

Total Project Cost (TPC) range: $320-395M

The next-generation CMB-S4 MIE project, CD-0 approved on 7/25/2019, is being planned as a partnership with the National Science Foundation (NSF), with DOE roles led by Lawrence Berkeley National Laboratory. CMB-S4 will consist of an array of small and large telescopes working in concert at two locations: the NSF Amundsen-Scott South Pole Station and the Atacama high desert in Chile. Both arrays are required to reach full science capabilities. The project is developing a design that will carry out the science goals within the available infrastructure and logistics capabilities at the sites.

Accelerator Complex Enhancement - Main Injector + Target (ACE-MI+T)

Total Project Cost (TPC) range: TBD

The Main Injector (MI) accelerator at Fermilab is used to supply the NOvA experiment and later the LBNF neutrino beamlines with protons. Decreasing the cycle of the MI from 1.2 seconds to 0.6 seconds will increase the power to the neutrino beam from 1200 kW to 2100 kW after Proton Improvement Project Phase II (PIP-II) begins operation. The MI power and radiofrequency acceleration systems will be upgraded to support the shorter cycle time. In addition, MI quadrupole magnets need to be replaced to ensure reliability. New beam monitoring and columniation are needed to reduce beam losses. The LBNF target and horns will need to be upgraded to support the high beam power.

Advanced Accelerator Test Facilities

Total Project Cost (TPC) range: TBD

The HEP General Accelerator Research and Development (GARD) subprogram supports R&D on Advanced Accelerator Concepts (AAC) which explore potentially revolutionary concepts and technologies for making future accelerators/colliders smaller and more affordable. Current R&D efforts include laser-driven plasma wakefield acceleration (LWFA), particle-beam-driven plasma wakefield acceleration (PWFA). To affirm the advanced acceleration concepts are a feasible technology for future e+e- collider over the next decade or beyond, a well-orchestrated program of integrated design studies (IDS) and experimental demonstrations is essential. This IDS, which will develop a self-consistent set of parameters for a linear collider, will be conducted alongside the experimental demonstrations, feeding insights back into the experimental design as new results emerge. The initial experimental phase should emphasize the demonstration of high-fidelity of all individual components necessary for acceleration in a single-stage module, such as achieving a high-gradient, high capture efficiency and maintaining low emittance, ensuring low energy spread, and securing high stability, and followed by a staged test featuring two or more integrated demonstrator modules. This intertwined approach of IDS and experimental demonstrations will propel our understanding of advanced acceleration concepts, setting the stage for significant advancements within the next decade.

DUNE High Power Far Detector Upgrade

Total Project Cost (TPC) range: TBD

The DUNE experiment has several primary physics goals: the determination of the mass hierarchy, the discovery of CP violation in neutrinos, and observation of supernova neutrinos. Discoveries need to be followed up by detailed measurements that can confirm the interpretation of the results, but neutrino experiments are always limited by the small probability of neutrino interactions. This can be addressed by either more neutrinos or more target mass. Other projects in the list will increase the neutrino flux to DUNE. One or more additional neutrino detectors can be accommodated at SURF. The evolution of technology will mean that there is an opportunity to build a more effective detector(s) in the 2030's than the current ones.

Future Energy Frontier Colliders

Total Project Cost (TPC) range: TBD

During the last decade, the international particle physics community has been coordinating on the possibility to construct a larger-scale next-generation particle collider to further advance research being studied at the LHC. Two leading initiatives are under consideration, each focusing on building an electron-positron (ee) Higgs factory that uses the Higgs boson as a tool for new scientific discoveries: 1) a Future Circular Collider (FCC) and 2) an International Linear Collider (ILC). The FCC-ee is a 90 km circular collider proposed to be hosted by CERN in the France-Swiss region, and the ILC is a 20 km linear collider where multilateral intergovernmental discussions have been ongoing for Japan to consider hosting the facility. If built, the FCC-ee and ILC would each consist of the collider and related infrastructure with up to four and two experiment detectors, respectively. Currently, CERN with its international partners, including DOE, are studying the technical and financial feasibility of the FCC-ee in which results are expected to be available by the next update of the European Strategy for Particle Physics in 2026. Discussions on proceeding with the ILC are also expected on that same timeframe and would depend on whether it is feasible for CERN and international partners to move forward with the FCC-ee. Longer-term and beyond the 2050 timeframe, conceptual designs are being considered to build 1) a future circular hadron collider (FCC-hh) at CERN with an energy of at least 100 TeV and 2) a staged 3-10 TeV muon collider of 10 km circumference and where a host laboratory still needs to be identified. If built after the FCC-ee, the FCC-hh would use the same tunnel as that of the FCC-ee.

DUNE High Power Near Detector Upgrade

Total Project Cost (TPC) range: TBD

The DUNE experiment will be statistics limited when it starts. After several years of taking data, the experiment will become limited by systematic errors. Upgrading the near detector to better understand the details of the neutrino interactions will allow the experiment to lower its systematic errors in tandem with the reduced statistical errors due to taking more data.

Stage-5 Spectroscopic Survey Instrument (Spec-S5)

Total Project Cost (TPC) range: TBD

Spec-S5 is a next-generation project to provide powerful tests of the physics of the universe beyond the Standard Model. It aims to discover the detailed time evolution of the expansion of all phases of the universe and what is causing its acceleration due to an unknown dark energy, provide theoretical tests and insights into the inflationary era at the beginning of the universe, and search for dark matter. The data will also enable searches for light relic particles and provide information on neutrino masses. Spec-S5 is a follow-on from the current Stage 4 Dark Energy Spectroscopic Instrument (DESI) project, the planned stage 4 Cosmic Microwave Background project (CMB-S4) and makes use of synergies and complementarities with the Vera C. Rubin Observatory stage 4 imaging LSST survey, enabling a factor of greater than 10 increase in science reach. The Spec-S5 survey will greatly increase the 3-dimensional map of galaxies, allowing measurements of quantum fluctuations imprinted on the galaxy maps and unprecedented access to very large scales of the universe which holds key information about primordial physics. Simulations and machine learning algorithms will be extensively used to extract the precision information from the high-density map of structure in the universe.

State of the art technologies in precision fibers, high-density robotic fiber positioners, gratings and sensor development including multi-amplifier sensing and low-read-noise CCDs build upon precursor projects. An existing telescope that has a least 4-meter diameter primary mirror will need to be identified to host the instrument.

Accelerator Complex Enhancement Booster Replacement (ACE-BR)
Total Project Cost (TPC) range: TBD
After the completion of PIP-II and ACE-MI+T, the Fermilab Booster will be the limiting factor of the accelerator complex performance. The Booster will also be 60 years old when PIP-II is completed. The integrated radiation dose to the machine will eventually render it unserviceable. Replacement of the Booster with a modern accelerator capable of minimizing beam losses will allow the LBNF beamline to reach 2.4 MW of beam power while also providing beam for a program of muon and neutrino physics at lower energies.