Excerpt from the Mission Need Statement for an Advanced Plasma Acceleration Facility

A. Statement of Mission Need

The mission of the High Energy Physics (HEP) program is to explore and to discover the laws of nature as they apply to the basic constituents of matter and the forces between them. To enable these discoveries, HEP supports the development of particle accelerators at increasingly high energies. Recent research on the acceleration of particles by strong wake-fields in plasma has demonstrated accelerating gradients of tens of billions of electron-volts (GeV) per meter, several hundred times higher than in the metal structures currently used for accelerators. This technology holds great promise for dramatic reduction of the size and cost of future accelerators, particularly high-energy electron-positron colliders. There are likely to be other science applications that can be realized at lower beam energies.

The Advanced Plasma Acceleration Facility (APAF) will be an experimental user facility for advancing the development of plasma wake-field acceleration. It will provide short, intense pulses of electrons or laser radiation to excite plasma wake-fields with sufficient amplitude to accelerate electrons by 10 GeV or more in approximately one-half meter of plasma. The APAF will be designed to address critical technical issues for very compact, multi-TeV, plasma-based accelerators. Among these issues are: high accelerating gradients; electrical efficiency; operating plasma accelerating modules in series to achieve high beam energies; and quality of the accelerated beam.

B. Analysis to Support Mission Need

The Tevatron collider at Fermilab is currently the highest energy accelerator in the world. It collides beams of protons and antiprotons with a total energy of about 2 TeV. In 2008 the Large Hadron Collider (LHC), which is currently nearing completion at CERN, is scheduled to begin accelerating beams of protons to a total energy of 14 TeV. Because protons are composite particles, the LHC energy will allow the production of particle states up to about 5 TeV.

The next high energy accelerator proposed after the LHC is an electron-positron collider, the International Linear Collider (ILC). The initial phase of the ILC is envisioned to have a total energy of 500 GeV, with the possibility of a subsequent increase in the energy to 1 TeV. The ILC would use superconducting niobium structures with an average accelerating gradient of 31.5 million electron-volts per meter, and the overall length would be 31 km.

Both the LHC and the ILC are multi-billion dollar investments, due to the extensive civil construction needed to house the accelerators, and industrial-scale production of advanced technology components. An accelerating gradient significantly stronger than that of the ILC will be essential for keeping the size and cost of future high-energy colliders in an affordable range.

For over two decades the Office of High Energy Physics (OHEP) has supported research in the acceleration of electrons by strong wake-fields in plasma. Recent achievements of this R&D program have been notable, particularly the laser acceleration of electron beams to 1 GeV in 3 cm of plasma by the Laser Optics and Accelerator Systems Integrated Studies (LOASIS) group at LBNL, and the energy doubling of a 42 GeV electron beam in a meter of plasma at SLAC's Final Focus Test Beam (FFTB) facility. The accelerating gradients achieved are tens of GeV per meter, approximately a thousand times higher than the design gradient for the ILC.

In May 2007 OHEP convened an external committee to review the Advanced Accelerator R&D (AARD) Program, as recommended by the HEP Advisory Panel's Subpanel on the Assessment of AARD in August 2006. The review committee recognized the "…recent, exceptional developments in long-term particle acceleration R&D," stated that "The time may be right for increased support to these few promising areas…", and recommended that OHEP "…should consider strategies to capitalize on its long-term investment and to realize multi-TeV acceleration to reduce space and cost of possible future accelerators."

OHEP has accepted this recommendation and identified plasma acceleration as a promising technology for increased investment. There are two complementary approaches.

Option 1: Construct a facility for experimental studies of electron-beam-driven wake- field acceleration. The functional capability of the former FFTB facility at SLAC, which was dismantled to accommodate Linac Coherent Light Source (LCLS) construction, could be recreated in the SLAC linac tunnel. Here the frontier of beam-driven plasma acceleration could continue to be advanced, moving beyond the energy-doubling demonstration to a demonstration of high-gradient plasma wake-field acceleration of a quality electron beam to 50 GeV. With the addition of a positron pulse compressor to the linac, plasma wake-field acceleration of a high-quality positron beam to 50 GeV could also be demonstrated. Acceleration by beam-induced wakes in dielectric structures could also be pursued, as well as beam instrumentation tests.

Option 2: Construct a facility for experimental studies of laser-driven wake-field acceleration. The LOASIS facility at LBNL could be upgraded by adding a Petawatt- class laser to allow the demonstration of a 10 GeV acceleration module as a building block for a TeV collider, and a factor of ten improvement over the current world-leading facility. In addition, the resulting 10 GeV electron beam could be utilized for testing HEP detectors and, in combination with the Petawatt laser, for forefront experiments in non-linear quantum electrodynamics.

Option 3: Pursue both Option 1 and Option 2. Both the particle-beam-driven and laser-driven approaches would be developed. This option would increase the probability of success and reduce the time for eventually realizing high energy plasma-based accelerators.

Option 4: Continue program at present scale with existing facilities. Physics studies of plasma wake-field acceleration driven by low-energy electrons would continue at the Accelerator Test Facility at BNL. Without a plasma wake-field facility at SLAC, there would be no capability for developing positron acceleration. Studies of laser-driven wake-field acceleration would continue at LOASIS, including series operation of multiple 1-GeV acceleration stages. This program would not provide a path to a TeV- scale collider.

C. Importance of Mission Need and Impact if Not Approved

A TeV-scale, or perhaps multi-TeV, electron-positron collider will be needed to understand and pursue discoveries made at the LHC. Plasma wake-field acceleration holds great promise for making such colliders affordable. However, the current research and development program cannot support a proof-of-principle demonstration or a conceptual design at this energy scale. An Advanced Plasma Acceleration Facility is needed to make the next step in development of these technologies.

If an APAF is not approved, progress towards an affordable, multi-TeV electron-positron collider will not meet the needs of High Energy Physics.

E. Applicable Conditions and Interfaces

The proposed schedule for construction of Option 1 at SLAC was developed to be compatible with the anticipated LCLS construction and operating plans. Following the construction phase, Option 1 is designed to operate independently of LCLS. Construction and operation of Option 2 at LBNL would be independent of all other projects and facility operations at the laboratory.

G. Development Plan

Option 1 at SLAC would require very little development, as it primarily involves reconfiguring the linac to relocate existing components from the dismantled FFTB to a new location. The most significant new component would be a positron pulse compressor, and that would be nearly identical to the existing electron compressor.

Progress on laser-driven plasma wake-field acceleration depends directly on the development of intense, short-pulse, high-average-power lasers. The major cost item for Option 2 at LBNL is a 1-Petawatt, 1-Hertz laser, which is slightly beyond the current state of the art. The laser would be developed to LBNL specifications by a qualified commercial vendor under a fixed-price sub-contract.