Project X Experimental Program
Summary

Accelerator-based experiments at the Intensity Frontier are now poised to make absolutely central advances toward understanding some of the most fundamental scientific questions of our time. Are there new forces of nature, new properties of matter, or new dimensions? Project X will be a unique facility for the exploration of Intensity Frontier phenomena. The combination of multi-MW beam power available at a variety of energies, beam formats tailored to the needs of individual experiments, and recent advances in detector technologies will enable a suite of experiments unrivaled in the world. The principal strength of the staged Project X experimental program is that it represents a broad assault with multiple probes of mass-scale reach beyond foreseeable colliders and sensitivities beyond competing initiatives at intensity frontier facilities worldwide.

Science

The experimental program enabled by the full scope of Project X builds on current investments in the U.S. Intensity Frontier experimental program including LBNE, the Fermilab muon campus, Fermilab short-baseline neutrino experiments, and electric dipole moment experiments. It offers opportunities to extend these programs with new initiatives to achieve a comprehensive exploration of these fundamental questions:

New forces in nature: Through the pursuit of interactions that violate lepton flavor symmetries (e.g. $\mu^- A \rightarrow e^- A$) and baryon number (e.g. neutron-antineutron oscillations), as well as those revealing new symmetries connected to the enigma of flavor-changing neutral currents.

New properties of matter: Through discovery and measurement of matter-antimatter asymmetries among neutrino oscillations and rare process (e.g. $K_L \rightarrow \pi^0 \nu\nu$), T-odd interactions manifest in electric dipole moments, and new flavor interactions evident in ultra-rare kaon and muon decays and interactions.

New dimensions: Through new quantum dimensions appearing via supersymmetric amplitudes manifest in ultra-rare processes where the standard model is highly suppressed (e.g. electric dipole moments), and new warped extra dimensions appearing through loop effects in ultra-rare processes (e.g. $K^+ \rightarrow \pi^+ \nu\nu$).

Project X enables scientific opportunities through the following experimental probes: neutrinos, muons, kaons, ultra-cold neutrons, and various techniques to measure electric dipole moments in nuclear and atomic systems. All these areas are supported in Stage 1 of Project X (see companion paper on Project X Accelerator Facility). In particular, the Stage 1 program supports a suite of experiments that taken together are absolutely central to the U.S. program.

Long Baseline Neutrinos: Project X Stage 1 will increase the beam power available on the LBNE production target which will nearly double from 700 to 1200 kW, significantly expanding the sensitivity to a non-zero CP violating phase in the neutrino sector.

Short Baseline Neutrinos: With respect to the current round of short-baseline experiments (e.g. MicroBooNE) Project X Stage 1 will *triple* the 8 GeV beam power available to future short baseline short baseline neutrino experiments. The increased beam power in the Main Injector will provide a 50% boost to the sensitivity of the nuSTORM initiative, which is an experiment embraced as important milestone by the worldwide neutrino factory and muon collider community.

Rare Muon Processes: Project X Stage 1 will provide the capability of delivering a *factor of ten* more beam power, from 8 to 80 kW, to the Mu2e conversion experiment ($\mu^- A \rightarrow e^- A$) currently under development. The beam timing flexibility afforded in Stage 1 will support conversion measurements with different muonic atomic states (A) which will be a crucial tool in elucidating the character of any new physics observed. The higher beam power and beam flexibility will also support new muon decay probes for physics beyond the Standard Model such as the search for $\mu \rightarrow 3e$ and $\mu^+ e^- \rightarrow \mu^- e^+$ oscillations.

Rare Kaon Decays: Project X Stage 1 will provide a capability of delivering more than double the beam power, from 30 to 75 kW, to the rare kaon decay experiment, ORKA (precision measurement of $K^+ \rightarrow \pi\nu\nu$) which is currently under consideration.

Neutron spallation target optimized for particle physics: Project X Stage 1 will provide up to 900 kW of beam power to a new suite of ultra-cold neutron and various electric dipole moment experiments driven by a spallation target facility optimized for particle physics. With a modest upgrade the spallation target could also drive a program of short baseline neutrino physics and coherent neutrino scattering physics.

Intense beams for hadronic physics: The intense proton, neutrino, and muon beams of Project X Stage 1 will enable a broad program studying hadronic physics. In addition to a new era of deep inelastic scattering and Drell-Yan production experiments, experiments aimed at hadron spectroscopy could observe glueballs and other exotic hadrons.

Stage 1 of Project X has substantial broader impacts beyond particle physics, including irradiation resources for materials important for advanced nuclear fuel cycle research and fusion research, and the capability to drive a muon spin rotation (muSR) materials research program.

Readiness

The LBNE and Mu2e both have received Critical Decision 1 and are ready to construct. The LBNE beamline is being designed to be upgradable to 2.3 MW, the goal of the Project X Reference Design. The Mu2e experiment would require upgrades to the target and capture solenoid systems to allow for operations at 80 kW. The ORKA experiment is a fourth generation of the stopped K^+ program successfully deployed at BNL and is ready to construct. The spallation target optimized for particle physics is a derivative of megawatt spallation targets optimized for material science now operating successfully in Europe, Japan, and the U.S. The nuSTORM initiative requires R&D that can be completed in advance of Project X Stage 1 operations.