THE HIGH INTENSITY HORIZON AT FERMILAB*

R. Tschirhart
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

Abstract

Fermilab's high intensity horizon is "Project-X" which is a US led initiative with strong international participation that aims to realize a next generation proton source that will dramatically extend the reach of Intensity Frontier research. The Project-X research program includes world leading sensitivity in long-baseline and short-baseline neutrino experiments, a rich program of ultra-rare muon and kaon decays, opportunities for next-generation electric dipole moment experiments and other nuclear/particle physics probes, and a platform to investigate technologies for next generation energy applications. A wide range of R&D activities has supported mission critical accelerator subsystems, such as high-gradient superconducting RF accelerating structures, efficient RF power systems, cryo-modules and cryogenic refrigeration plants, advanced beam diagnostics and instrumentation, high-power targetry, as well as the related infrastructure and civil construction preparing for a construction start of a staged program as early as 2017.

INTRODUCTION

A recent review panel [1] of the High Energy Physics Advisory Panel within the US identified three frontiers of scientific opportunity for the field of particle physics: the energy frontier, the intensity frontier and the cosmic frontier. "Project X", a proposed new high-intensity proton source at Fermilab [2], has the potential to be the flagship of discovery at the intensity frontier. Project X would deliver very high-power proton beams at energies ranging from 1.0(kinetic) GeV to 120 GeV. It would also offer unprecedented flexibility in the timing structure of beams (pulsed or continuous wave, varying gaps between pulses, fast or slow spill) and in a variety of simultaneously delivered secondary beams. These features would make Project X the foundation both for fundamentally new experiments and for significant advances in ongoing experimental programs in neutrino physics and the physics of ultra-rare processes.

Physics at the intensity frontier is closely linked with both the energy and the cosmic frontiers. Answers to the most challenging questions about the fundamental physics of the universe will come from combining what we learn from the most powerful and insightful observations at each of the three frontiers. Addressing most of the questions under investigation at the energy and cosmic frontiers also requires measurements at the intensity frontier.

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Understanding neutrinos and their masses, for example, may address the central question of the ultimate unification of forces. Matter-antimatter asymmetry in the behaviour of neutrinos might elucidate one of the deepest mysteries of physics: why do we live in a universe made only of matter, with no antimatter? Results from experiments now underway around the world will shape the future course of neutrino research. No matter what they find, Project X, with the world's most intense neutrino beams, will be key to the next steps in neutrino physics.

THE INTENSITY FRONTIER IN THE LHC ERA

Characterizing the properties (e.g. flavor couplings) and interactions of new particles sought after in the CERN Large Hadron Collider (LHC) research program will require measurements from experiments at the intensity frontier. If experiments at the LHC discover super-symmetry, for example, intensity-frontier searches have the potential to make critical distinctions among different models of this phenomenon. And if LHC experiments should fail to see new physics up to and near the TeV mass scale, the intensity frontier would be the only approach to access new physics that may exist beyond the mass scale reach of the LHC. Indeed as evident in Figure 1, LHC experiments[3] are now directly exploring the TeV scale with no evidence to date of phenomena beyond the Standard Model--which highlights the importance of Intensity Frontier experiments which can reach far beyond the TeV mass scale.

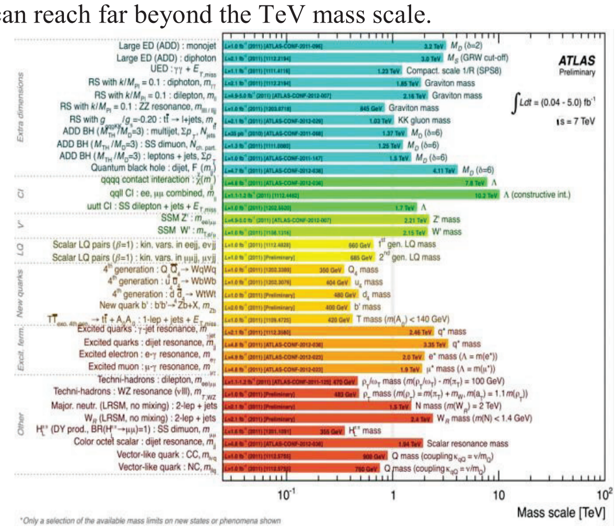

Figure 1: ATLAS/LHC limits on new physics models and the corresponding mass scales probed [3].

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HIGH INTENSITY BEAMS

High-intensity particle beams can advance the frontiers of particle physics wherever a major step in sensitivity requires extraordinary precision and clean, background-free experimental conditions. These beams for example drive the reach for many neutrino studies, such as long-baseline experiments which require precise understanding of the generated neutrino energy spectra in order to detect matter-antimatter asymmetry in neutrinos. These beams allow researchers to focus sharply on barely observable processes with great scientific significance, such as the high-priority search for the coherent conversion of muons to electrons. In experiments now limited by statistics, such as the search for the transition of a quark of one flavor to an identically charged quark of a different flavor, (flavor changing neutral currents) very high intensity beams make possible the precise measurements that are essential for discovery. They provide the exacting experimental conditions required by extremely challenging experiments, such as the search for the rare decays of kaons which require high duty-factor beam trains with very fast (<50 psec) pulses within the train. Precision measurement of the $K \rightarrow \pi\nu\bar{\nu}$ kaon decays are particularly promising probes of physics beyond well beyond the LHC's reach. Finally, these beams make possible experiments that may be crucial for a true understanding of physical phenomena such as electric dipole moments of atoms, a very incisive probe of matter-antimatter asymmetry at energy scales beyond the Standard Model.

PROJECT X

The concept of the Project X accelerator complex is illustrated in Figure 2, and opens the window on a whole spectrum of new experiments at the intensity frontier. The scientific opportunities provided by Project X are in four areas: neutrinos, muons, kaons, and fundamental physics using nuclear physics techniques. With the power of Project X, they all attain new, hitherto unattainable, capabilities for discovery. Project X would also represent a first step toward potential future particle physics facilities, such as a neutrino factory or an energy-frontier muon collider.

For many years Fermilab has operated both the highest-energy particle collider and the highest-intensity accelerator based neutrino beam in the world. Now the LHC has surpassed the Tevatron in energy and Japan's J-PARC facility is embarking on a long-baseline neutrino program in strong competition with the Fermilab program. In this international context, the US elementary particle physics community has adopted a strategic plan for the coming decades that emphasizes research on three frontiers: the energy frontier, the intensity frontier and the cosmic frontier. The plan recognizes that over the coming decades Fermilab will be the sole US site for accelerator-based particle physics research. Fermilab's strategy is fully aligned with the US plan. It features the development of a high-intensity proton source as the key to the long-term US program.

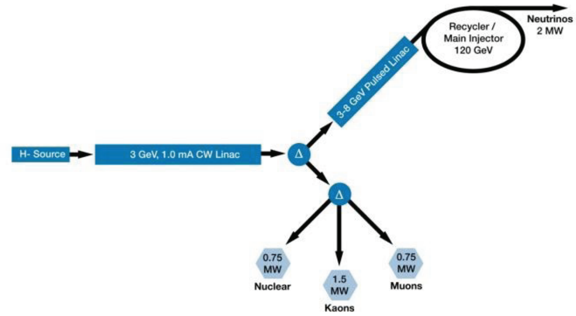

Figure 2: Project X, a high-power proton facility, would support world-leading programs in long-baseline neutrino physics and the physics of rare processes. Project X is based on a 3 GeV continuous-wave super-conducting H- linac. Further acceleration to 8 GeV, injected into Fermilab's existing Recycler/Main Injector complex, would support long-baseline neutrino experiments. Project X would provide 3.0 MW of total beam power to the 3 GeV program, simultaneously with 2 MW to a neutrino production target at 60-120 GeV and 200 kW at 8 GeV.

Project X is a multi-MW proton accelerator facility proposed for construction at Fermilab. It is based on an H- linear accelerator using superconducting RF technology. Project X would be the linchpin for future development of the Fermilab accelerator complex, providing long-term opportunities at both the intensity and energy frontiers. Project X would provide great flexibility for intensity-frontier physics, creating the opportunity for a long-term world leading program in neutrino physics and other beyond-the-standard-model phenomena. The technology [2] for Project X also opens opportunities beyond traditional particle physics applications, including:

- Accelerator-driven energy systems
- Rare isotope production for nuclear physics
- Neutron sources
- X-ray FELs
- Energy recovery linacs
- Muon facilities for materials research

The technology development for Project X is also closely aligned with the technologies required for a next generation lepton collider or neutrino factory if the on-going program motivates these new facilities.

Program:	Onset of NOvA operation in 2013	Stage-1: 1 GeV CW Linac driving Booster & Muon, EDM programs (MI>80 GeV)	Stage-2: Upgrade to 3 GeV CW Linac (MI>80 GeV)	Stage-3: Project X RDR (MI>60GeV)	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2300 kW	2300-4000 kW
8 GeV Neutrinos	15 kW + 0-50 kW**	0-40 kW* + 0-90 kW**	0-40 kW*	85 kW	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	85 kW	1000 kW
1-3 GeV Muon program	-----	80 kW	1000 kW	1000 kW	1000 kW
Kaon Program	0-30 kW** (<30% df from MI)	0-75 kW** (<45% df from MI)	1100 kW	1100 kW	1100 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
# Programs:	4	8	8	8	8
Total* power:	585-735 kW	1660-2240 kW	4230 kW	5490 kW	11300kW

Figure 3: Staging plan for Project X, where the full scope as defined in the Reference Design Report (RDR) is realized at stage (3). *Depends of the operating energy of the Main Injector (MI). **Depends on the whether a slow-spill period is present within the Main Injector cycle timeline, quantified by duty factor (df).

In response to the current challenging funding environment, The Project X collaboration has developed a staging plan with a robust suite of new physics at each stage culminating in the reference design at stage 3. Stage-1 substantially increases Main Injector beam power and doubles the number of research programs with the advent of a new high power 1 megawatt CW proton source. Stage-4, beyond the RDR, would be a large step forward for neutrino physics and a platform for developing a Muon Collider if motivated by the on-going LHC program.

SUMMARY

Project-X is an evolution of the best assets of the Fermilab accelerator complex with the revolution in super-conducting RF technology that will increase the proton beam power to the Fermilab research campus by an order of magnitude. Project X will likely be deployed in stages, where each stage of will raise many boats of the Intensity Frontier, with a full program scope of more than 20 world-leading particle physics experiments and an associated robust user community.

The necessary R&D to realize Project X is advancing well and could support a construction start this decade.

ACKNOWLEDGMENT

This report is based on many contributions from the Project X collaboration.

REFERENCES

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[2] Project X website: http://projectx.fnal.gov/

[3] Summary of ATLAS and CMS results presented at the Moriond 2012-Electroweak conference in La Thuile: (http://indico.in2p3.fr/conferenceDisplay.py?confId=6001)

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