Applications of High Intensity Superconducting Proton Accelerator (Project-X)

Fermilab research in particle physics covers all three interrelated frontiers: The Energy, The Intensity and The Cosmic. While being leader in the energy frontier for last decades, Fermilab has passed that baton to the Large Hadron Collider at CERN. However Fermilab is now vigorously focusing its future accelerator development on the intensity frontier and on required technological capabilities so that when the LHC delivers new results, the laboratory could return on a course to take a lead in precision measurement at the energy frontier.

Recent advances in superconducting radiofrequency (SRF) technology have made it possible to construct high-intensity proton accelerators with multi-milliamps of beam current and energies exceeding 1 GeV. Fermilab is developing a design of a High Intensity Proton Linac, known as Project-X, to support future High Energy Physics Programs at the intensity frontier. The present design of the Project-X linac could provide 2 Megawatt of Continuous Wave (CW) beam power at 3 GeV and higher pulsed power (either using a synchrotron or linac) at 8 GeV.

Fermilab hosted a workshop (http://conferences.fnal.gov/App-Proton-Accelerator/index.html) to explore the possibility of diversifying and maximizing the utilization of the proposed upgrade to the Fermilab accelerator complex and applying the technology developed for Project X to other areas of science and industrial application. The workshop explored the possibility of using this SRF linac either stand alone or as an injector to existing Fermilab accelerators for applications as diverse as:

- Production of high intensity proton beams for neutrino, muon and kaon physics
- Injector for a future muon collider and neutrino factory
- Accelerator-based schemes for nuclear energy applications
- Nuclear and material science and material production

The Project-X SRF linac would advance research in all of these areas. In the next sections we present the high level summary, the details could be found in other white papers (1-3) submitted to this workshop.

<u>a. Particle Physics</u>

A high power proton source in excess of two Megawatts at Fermilab would enable high precision experiments with neutrino, muon, kaon and neutron beams.

<u>Neutrino:</u> At the intensity frontier the Main Injector Neutrino Oscillation Search (MINOS) is an experiment currently performing higher precision measurement of neutrino oscillations. A higher power beam for under construction NOνA and the proposed Long-Baseline Neutrino Experiment (LBNE) would help map fundamental properties of neutrinos and search for matter-antimatter asymmetries among neutrinos. Evidence for matter-antimatter asymmetry in the neutrino sector could help us understand one of the most vexing problems in particle physics today.

<u>Muon:</u> The high power beam will enable measurements of the $\mu \rightarrow e$ conversion rate, search for ultra-rare muon decays and search for the muon electric dipole moment. These measurements are sensitive probes of the beyond the Standard Model physics.

<u>Kaon:</u> The proton beam power available from the Project-X linac can drive the next generation kaon experiments that can make precision measurement of ultra-rare kaon decays K◎◎◎◎to ~50 part per trillionand interference phenomena in the neutral kaon system approaching the Plank scale.

<u>Neutron:</u> Precision measurement of the neutron lifetime to determine up and down quark coupling and search for the neutron electric dipole moment are a few examples of physics that could provide some insight into new physics.

b. Muon Collider and Neutrino Factory:

At the energy frontier, a muon collider would have substantial advantages over either a hadron or an electron-positron collider: a) It has the same physics reach as a proton collider of ten times higher energy, b) the muon is more strongly coupled to the Higgs than is an electron by the square of the mass ratio, making it an ideal probe for Higgs studies, and c) the heavier muons emit little or no synchrotron radiation, making a high-energy circular muon collider energetically and economically feasible. To generate the quantity of muons required for a muon collider or neutrino factory a multi-megaWatt proton beam will be needed. The Project-X linac can be configured to produce 8 GeV proton beam that could be used as a 1^{st} step to the muon collider accelerator chain.

c. Nuclear Energy Application: Accelerator Driven Sub-Critical Systems

At present about 18 Trillion Units (1kWH) of electricity is annually produced in the world which is nearly 40% of humanity's total energy needs. Fossil fuel based electricity generation, which at present is about 60 % of the total, results in nearly 10 Giga-tons of carbon dioxide being added annually to the atmosphere causing undesirable consequences. With total worldwide demand for electricity projected to rise by 75% over the next 25 years, the burden of energy production and carbon loading will increase dramatically. Clearly, from amongst non-carbon based sources, nuclear energy is a good option to meet the base load needs of humanity, if an acceptable solution can be found to tackle nuclear waste problem posed by minor actinides (MA) and long-lived fission products (LLFP). In this context, main difficulty of Uranium based reactors can be traced to poor neutron yield of the fission process. A way out is to integrate the fission process to neutron rich spallation process by using a high energy proton beam falling on a high Z material (e.g.; Pb, W, U, Th) that is surrounded by a sub-critical reactor. When these neutrons multiply -through finite fission chain reactions in a sub-critical reactor- there is an overall energy gain. Such accelerator driven systems (ADS) have the capability to incinerate MA and transmute LLFP thus reducing the radio-toxicity of waste and also help in the use of Thorium as an alternate *proliferation resistant* nuclear fuel. An ADS system would typically require a proton beam of ~1-2 GeV, ~1-10 mA and a sub-critical core based on fast neutrons or thermal neutrons or a combination thereof. Work is going on different facets of this program both in US and India and a partnership between US DoE and Indian DAE would be most appropriate in the light of proposed projects in the two countries.

Significant Accelerator Driven Sub-Critical system (ADS) efforts exist in many countries in Europe, Japan, China and India. The first step towards realizing ADS for nuclear energy production is an accelerator that can reliably deliver, almost loss free, a high power beam to a target. Critical accelerator physics and beam halo formation studies will be needed for proton energies below 50 MeV and 10's of milliamperes of beam current. These studies will be undertaken as part of Project X. The SRF linac technology makes the construction and operation of this accelerator cost effective and more feasible. Before getting into details of targeting, beam reactor interface and reactor issues in the Fermilab program, one must demonstrate the stable operation of such an accelerator to achieve the required ADS performance. Target, accelerator/subcritical interface, and subcritical designs also need development, and could be done at collaborating laboratories, expert in those areas. The Project-X planned 2 MW CW beam at 3 GeV would mark a beginning as an ADS technology demonstration project, being able to produce about 100MW_{el} of power. This accelerator could also become a platform for ADS technology transfer to industry (in collaboration with a reactor expert laboratory) if such a technology becomes viable in a laboratory environment. Project X can be designed in such a way as to provide demonstration and/or verification of critical accelerator technologies required to support ADS development, including upgrades approaching 10 MW operations, should this become a U.S. national priority.

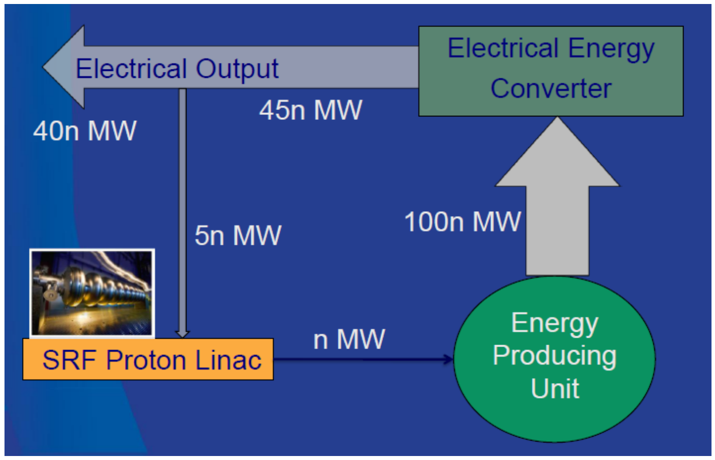

Fig. 3 Nuclear Energy Application of SRF Linac

d. Material Science and Medicine

High power beam from the Project-X linac can be used for material R&D and medical isotope production, especially where accelerator offers an alternate way to make them. The irradiation capability of this beam could support a) closing of the nuclear fuel cycle, b) fusion reactor related development and c) MW class accelerator target development. The beam can also be used for fundamental studies of radiation damage to understand the how radiation changes micro-structure in materials. This linac could also be used to develop an ISOL facility for nuclear medicine. For example, ^{225}Ac is urgently needed for clinical trials for cancer and HIV treatment research but now available in very limited quantities.