Project-X: A Powerful Facility for Particle Physics

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Physics for Everyone
December 7, 2011
Questions I Will Try to Answer

• What brings us to this point?
• What is Project-X and how does it work?
• Why do we need Project-X?
• What else can we do with Project-X?
Fermilab’s Legacy of Building Accelerators to Answer the Big Questions
Main Ring Construction (1969-1971)

- Main Ring Groundbreaking: Oct. 3, 1969
- Celebration of last Main Ring magnet: April 16, 1971

Project approved: July 1979

Last magnet installed: March 18, 1983
Antiproton Source Construction (1983-1985)

Antiproton Groundbreaking: Aug. 16, 1983
First antiprotons collected: Sep. 6, 1985
Main Injector Construction (1993-1999)

Dedication: June 1, 1999

Groundbreaking: March 22, 1993
Particle Physics is all about the Big Questions

- How did the universe begin?
- Why are we here and where are we going?
- What is the universe made of?
- How many forces are at work in the universe?
We Have Assembled a Remarkably Powerful Picture of the Subatomic World
Fermilab has Played a Big Role in Answering the Big Questions

- What are the basic building blocks of matter?
- How many families of quarks & leptons are there?
- How do the basic building blocks interact with one another?
- What are the basic forces of nature and how do they act?
- Fermilab has played a central role in constructing this picture:
  - Bottom, top quarks and tau neutrino discovered/observed at Fermilab
But, Big Questions Remain!

- What is the origin of mass?
- Why are there so many kinds of particles?
- Is there a deeper connection between all these building blocks?
- Do all forces become one?
- What do neutrinos tell us?
- What happened to all the antimatter?
- What is dark matter?
- Mystery of dark energy?

*Answering these questions requires a new, powerful, accelerator at Fermilab: Project-X*
Energy vs. Intensity

• When you think about particle accelerators you may think of the really big ones that strive for the highest energies:

• The future program at Fermilab relies on making the world’s most intense beams of particles, and exploring the physics that can only be studied with such extremely intense beams

S. Henderson, Dec. 7, 2011
Physics at the Intensity Frontier
Rare Decays and Rare Processes

- Example: a Muon cannot “morph” into an Electron, as far as we know (known processes too small to observe)
- By producing a huge number of muons, we will search for “muon to electron conversion”, which if seen, indicates startling new physics, perhaps pointing the way to a deeper structure
- Fermilab will study $1,000,000,000,000,000,000$ muons searching for this...a number equal to the grains of sand on all the world’s beaches!
- **We need a new, very powerful accelerator to search for these very rare processes!**
How do we think about these rare decays?
Neutrinos

• Neutrinos are very elusive. We are just beginning to understand what they are and how they work.
• They are everywhere!
  • ~100 trillion neutrinos zip through each person every second.
  • There are one billion neutrinos for each proton or electron in the universe.
Intense Beams of Neutrinos

- They are weird!
  - They hardly interact with anything – zipping through earth
  - They weigh almost nothing (but not nothing)
  - They “morph” over large distances from one to another
  - Do they travel faster than the speed of light?
- To make sense of them we need to produce them in huge numbers in the lab
- *We need a new, very powerful accelerator, to make sense of neutrinos!*
Long Baseline Neutrino Experiments

NOvA

MINOS

LBNE
Fermilab’s Program

- Fermilab’s accelerator-based program is focused on the **Intensity Frontier**
- We intend to build the accelerator facilities, build the experimental facilities and carry out the experiments that will enable Fermilab to be the **leader on the Intensity Frontier**
- Just as Fermilab’s Tevatron, built 30 years ago, provided an incredibly powerful platform that enabled three decades of groundbreaking particle physics research
- We are now planning to build the next powerful facility to enable the next three decades of world-leading research with Project-X
The Project-X Accelerator Facility
Project-X Will Be….

- a state-of-the-art, world-leading accelerator facility at Fermilab
- …providing the world’s most powerful beams of protons
- …to make the world’s most intense beams of neutrinos, muons, kaons and rare nuclei
- …which will cement Fermilab’s position as the world-leader in the Intensity Frontier for decades to come
- …and will also provide a platform for the next accelerator at Fermilab beyond PX
News and Plans

• We are busy building the scientific case, and making that case with our funding agency and the particle physics community
• Last week the physics community came together to assess the scientific opportunities at the Intensity Frontier
• We are advancing Project X technology through a vigorous R&D Program in many areas
• We want to be ready for construction by 2016
• Project X is a national project with international participation. Collaboration is extremely important to the success of Project X!
The Project-X Accelerator

Number of Protons vs Time

H- Source → 3 GeV, 1.0 mA CW Linac → Δ

Number of Protons vs Time

3-8 GeV Pulsed Linac

>2 MW @ 120 GeV
3 MW @ 3 GeV
150 kW @ 8 GeV

Recycler / Main Injector
120 GeV

Neutrinos
2 MW

0.75 MW
Nuclear

0.75 MW
Muons

1.5 MW
Kaons

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Fermilab’s Accelerator Complex in the Project X Era
Project X 3-GeV Experimental Campus

Proposed location of Project X
3-GeV experimental campus

1. Proton beam from 3-GeV linac
2. Switchyard: beam distribution
3. Charged kaon decay experiment
4. Neutral kaon decay experiment
5. Experiments with atomic nuclei
6. Advanced muon-to-electron conversion experiment
7. Wilson Hall and existing buildings

Project X would provide a 3-GeV proton beam for experiments with kaons, muons, and atomic nuclei.
In the World of High-Power Proton Accelerators Project-X will be Unique

- Highest proton beam power on the planet
- Broadest range of proton beam energies available: 1-120 GeV
- Ability to provide beams to multiple experiments simultaneously
- Ability to tailor the beam properties to the needs of each experiment
- Upgradeable to very high power

*Project-X is the ideal machine for intensity-frontier physics*
Project-X Will Provide 5 MW of Beam Power: How Much is a MegaWatt?

Electric locomotive: 5 MW traction power

5 MW powers ~4000 homes

10 MW solar power plant
High Power Proton Accelerators: Some History

- 1950s: Materials Test Accelerator
- 1972: LANSCE
- 1974: PSI
- 1985: ISIS
- 1999: Main Injector
- 2006: SNS
The Landscape of High Power Proton Accelerators
Project-X Beam Power Compared

Muon, neutron, kaon facilities

Long Baseline Neutrino facilities

Beam Power (MegaWatt)

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<th>Facility</th>
<th>Project-X</th>
<th>PSI</th>
<th>SNS</th>
<th>J-PARC</th>
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How Project-X Works
Making a high power beam requires several ingredients

- Source of particles
- A way to control the detailed distribution of beam particles in time (beam chopper system)
- A way to accelerate the particles: Superconducting Radiofrequency Accelerator
- A place to deliver the beam (a target)
- Project X builds upon tremendous developments in the last two decades on Superconducting Radiofrequency Accelerators
Superconductivity

- Normal conducting metals heat up when an electrical current is passed through them.

- Superconductors are amazing materials that don’t heat up when an electrical current is passed through them.
- Some materials become superconducting when they are cooled to a few degrees above absolute zero (−460 °F).
- This means they can carry tremendous electrical currents.
Normal Conductors vs. Superconductors
Normal Conducting Accelerating Cavity

- 1 Million Volts/meter;
- ~2 Million Watts RF power dissipated
- Long and inefficient

Super Conducting Accelerating Cavity

- 15 Million Volts/meter
- ~10 Watts RF power dissipated
- Short and efficient
Superconducting Linear Accelerator for Project-X

[Image of a long, yellow cylindrical device with components labeled such as Pivot point, Stepper motor, and Slow tuner arm.]
Project-X: A Powerful Facility for Particle Physics and Beyond
What else can we do with Project-X?

- A multi-MegaWatt high energy proton accelerator is a national resource, with potential application that goes beyond particle physics.
- Such facilities are sufficiently expensive that the U.S. will not invest in multiple facilities with duplicative capabilities.
- With proper design we can share Project-X beams with non-particle physics activities.
- Some of these non-particle physics activities can have a very big impact on problems of national importance, like energy.
Applications of High Power Proton Accelerators

Materials Science
- Neutron/Muons to develop materials for energy

Energy & Environment
- Nuclear Energy
- Fusion Energy

Particle Physics
- Intensity Frontier experiments

Medicine
- Isotopes for medical diagnosis

Nuclear Physics
- Astrophysics (origin of chemical elements)

National Security
- Proton Radiography
Some materials used in nuclear reactors suffer from degraded properties after many years in the reactor environment. Materials for next generation nuclear reactors need an order of magnitude greater radiation resistance than those in use today. One can build a facility to study materials in extreme radiation environments.
Accelerator Driven Reactors

High-power, highly reliable proton accelerator

Neutron-producing target system

Subcritical nuclear reactor
- Designed to be incapable of maintaining a chain reaction
Applications: Accelerator Driven Subcritical Reactor Systems

- Accelerator Driven Reactors may be useful for
  - Generating electrical power with inherent safety (just shut off the accelerator)
  - Transforming highly radioactive nuclear waste to much less radioactive forms to help solve the country’s nuclear waste problem

- Project-X could help to develop this technology for use elsewhere
Applications: Neutron Imaging

• Today’s highest-power proton accelerators are utilized to produce neutron and muon beams for materials science
• Neutrons have unique properties, which make them very useful for imaging

Neutron imaging of a BMW engine showing oil flow and lubrication (B. Schillinger et. al., Physica B 385 (2006) 921)
Project-X Will Be a Very Versatile Tool

- Rare Kaon Decays
- Long-baseline Neutrinos
- Short-baseline Neutrinos
- Muon Physics
- Standard Model tests with Nuclei
- Materials Irradiation
- Cold muons/neutrons for materials sci.
- Accelerator Driven Systems
Conclusion

• Fermilab is going after the most exciting questions in particle physics, the most interesting questions about the nature and future of our universe.

• We are planning to build a next generation, world’s most powerful proton accelerator to power Fermilab and the nation’s particle physics program for the next three decades.
There are complementary approaches:

The Energy Frontier exploits Einstein’s mass-energy relation

\[ E = mc^2 \]

appearance of real new particles

The Intensity Frontier exploits Heisenberg’s uncertainty principle

\[ \Delta E \Delta t \geq \hbar \]

appearance of virtual new particles

High energy crucial

High intensity crucial

Feynman’s tools
Test Facilities: ASTA and CMTF

- Advanced Superconducting Test Accelerator (ASTA) under construction at NML
- Cryomodule Test Facility (CTF) to allow cryogenic and RF testing of assembled cryomodules
Project X Reference Design

- Unique capability to provide multi-MW beams to multiple experiments simultaneously, with variable bunch formats.
- Provides U.S. Intensity Frontier leadership for decades!

- >2 MW @ 120 GeV
- 3 MW @ 3 GeV
- 150 kW @ 8 GeV
Fermilab SRF infrastructure

- VTS
- Cavity tuning machine
- HTS
- String Assembly
- MP9 Clean Room
- Final Assembly
- 1st U.S. built ILC/PX Cryomodule
- 1st Dressed Cavity

MIT Colloquium - S. Henderson