Project X Facility Description and Plan

Steve Holmes

Fermilab Physics Advisory Committee
June 17, 2008
Outline

• Strategic Context
• Project X Facility Overview
• Project X Research, Design, and Development Plan
• Project X and Other Future Facilities
Fermilab is the sole remaining U.S. laboratory providing facilities in support of accelerator-based Elementary Particle Physics.

The Fermilab long-term plan incorporates three strategic directions:

- Colliders: $pp$, $pp$, $e^+e^-$, $\mu^+\mu^-$
- Telescopes; Underground experiments;
- Intense proton source: $\nu$, $\mu$, $K$, $\bar{p}$ beams;
Strategic Context
P5 Recommendations

- Energy Frontier
  - The panel recommends for the near future a broad accelerator and detector R&D program for lepton colliders that includes continued R&D on ILC ... The panel also recommends R&D for alternative accelerator technologies, to permit an informed choice when the lepton collider energy is established.
Strategic Context
P5 Recommendations

• Intensity Frontier
  – The panel recommends an R&D program in the immediate future to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL and recommends carrying out R&D on the technologies for a large multi-purpose neutrino and proton decay detector.
  – A neutrino program with a multi-megawatt proton source would be a stepping stone toward a future neutrino source, such as a neutrino factory based on a muon storage ring... This in turn could position the US program to develop a muon collider as a long-term means to return to the energy frontier in the US.
Project X is a high intensity proton facility aimed at supporting a world leading program in neutrinos and rare decays.

- **8 GeV slow spill**
  - 200 kW
  - 2.2E14 protons/1.4 sec
  - Flavor and low energy neutrino program

- **120 GeV fast extraction**
  - 2.3 MW
  - 1.7E14 protons/1.4 sec

**Main Injector**
- 1.4 sec cycle
- 0.4 GeV to 8 GeV

**Recycler**
- 3 linac pulse/fill
- Single turn transfer @ 8 GeV

**Front End**
- ILC Style 8 GeV H⁻ Linac:
  - 9mA x 1 msec x 5 Hz

**DUSEL later**

NOvA initially,
The Project X facility scope includes:

- A new 8 GeV, superconducting, H\(^-\) linac capable of delivering 360 kW of beam power;
- A new beamline for transport of 8 GeV H\(^-\) from the linac to the Recycler Ring;
- Modifications to the Recycler required for 8 GeV H\(^-\) injection, accumulation, and delivery of protons to the Main Injector;
- Modifications to existing beamlines to support transfer of 8 GeV protons from the Recycler to the Main Injector;
- Modifications to the Main Injector to support acceleration and extraction of high intensity proton beams over the range 60-120 GeV;
- Modifications to the NuMI facility to support operations at 2 MW beam power;
- Modifications to the Recycler to support a new extraction system for delivery of 8 GeV protons in support of a dedicated flavor program.
## Project X Overview
### High Level Performance Goals

<table>
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<tr>
<th>Component</th>
<th>Particle Type</th>
<th>Beam Kinetic Energy</th>
<th>Particles per pulse</th>
<th>Pulse rate</th>
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<td>8.0 GeV</td>
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<td>5 Hz</td>
<td>360 kW</td>
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<td><strong>Recycler</strong></td>
<td>Protons</td>
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<td>120 GeV</td>
<td>1.7×10^{14}</td>
<td>2300 kW</td>
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Project X Overview
Provisional Siting
The goal of the Project X Research Design and Development (RD&D) program is to provide support for a Critical Decision 0 (CD-0) in 2009, leading to a CD-2 in 2011/12.
- Design and technical component development;
- Fully developed baseline scope, cost estimate, and schedule;
- Formation of a multi-institutional collaboration capable of executing both the RD&D plan and the follow-on construction project.

The primary technical goal is a complete facility design that meets the needs of the US research program, as established via CD-0.
- 2 MW of beam power over the range 60 – 120 GeV,
- Simultaneous with at least 100 kW of beam power at 8 GeV
- Compatibility with future upgrades to >2 MW at 8 GeV
Project X RD&D Plan
Program Goals

- Alignment with future accelerator facilities
  - ILC and SRF programs:
    - Development of shared technologies to the benefit of both efforts
    - Project X linac designed to accommodate accelerating gradients in the range 23.6 – 31.5 MV/m (XFEL – ILC)
  - Muon facilities
    - Develop upgrade concept for the Project X linac aimed at >2 MW
    - Develop a performance specification for a Proton Driver supporting a Neutrino Factory and Muon collider, consistent with Project X concepts.
Project X
360 kW 8GeV Linac
20 Klystrons (2 types)
436 SC Cavities
56 Cryomodules

325 MHz 0.12-0.42 GeV
3 Klystrons (JPARC 2.5 MW)
42 Triple Spoke Resonators
7 Cryomodules

325 MHz 0-10 MeV
1 Klystron (JPARC 2.5 MW)
16 RT Cavities

325 MHz 10-120 MeV
1 Klystron (JPARC 2.5 MW)
51 Single Spoke Resonators
5 Cryomodules

360 kW 8GeV Linac
20 Klystrons (2 types)
436 SC Cavities
56 Cryomodules

1300 MHz 0.42-1.2 GeV
2 Klystrons (ILC 10 MW MBK)
56 Squeezed Cavities (β=0.81)
7 Cryomodules (8 cav., 4 quads)

1300 MHz 1.2-8.0 GeV
13 Klystrons (ILC 10 MW MBK)
287 ILC-identical Cavities
37 ILC-like Cryomodules

Modulator

ILC LINAC
8 Cavities - 4 quads / Cryomodule

ILC1

8 Cavities-1 quad / Cryomodule
Project X RD&D Plan

Strategy

• Working backwards (probable delay if/when FY09 CR):
  - FY12: CD-3 – Start Construction
  - FY11: CD-2 – Establish Baseline
  - FY10: CD-1 – Establish Baseline Range
    ➢ Requires a complete Conceptual Design Report
  - FY09 (spring): CD-0
    ➢ Requires new cost (range) estimate which will be reviewed by DOE

• FY2008 Goals
  - Establish basic performance parameters
  - Develop design concept sufficient to from basis of a cost estimate
  - Understand how/if the linac could support a 2+ MW upgrade
  - Form Project X RD&D Collaboration and establish work assignments for FY09
Project X RD&D Strategy

Preliminaries

- Proton Driver Design Studies over 2002-2004
  - Director’s Review in March 2005

- Project X Preliminary Report - August 1, 2007
  - Reviewed by Fermilab Accelerator Advisory Committee
    ➢ “We congratulate the Project X team on an innovative design... The committee therefore very strongly supports the work that is planned for Project-X.”
    [Link](http://projectx.fnal.gov/AACReview/ProjectXAacReport.pdf)

- Project X Accelerator Physics and Technology Workshop - Nov. 12-13, 2007
  - 175 attendees from 28 institutions.
    [Link](http://projectx.fnal.gov/Workshop/ProjectXWorkshopReport.pdf)

- Project X presentation to P5 – Jan. 31, 2008
  [Link](http://www.fnal.gov/directorate/program_planning/P5/P5_Jan2008/Agenda.html)
Project X RD&D Strategy
Technical Elements

• **Requirements** - develop major system requirements
  - Eight major systems
  - 17 base requirements
  - 68 derived requirements

• **Issues** - identify issues arising from the requirements

• **Elements** - define the elements of an RD&D plan that
  - Addresses the issues arising from the requirements
  - Are directed towards a completion of Conceptual Design Report

• **Resources and Schedule** - estimate:
  - The resources required to complete the RD&D plan
  - The schedule required to complete the RD&D plan

Note: The Project X RD&D strategy assumes the existence of ILC, SRF, and HINS programs.
Project X RD&D Strategy

Project X Major Systems

- A front end linac operating at 325 MHz.
- An ILC-like linac operating at 1300 MHz.
- An 8 GeV transfer line and H- Injection system.
- The Recycler operating as a stripping ring/proton accumulator.
- The Main Injector acting as a rapid cycling accelerator.
- A slow extraction system from the Recycler.
- 120 GeV Neutrino beamline.
- Civil Construction and Utilities
- Controls
# Project X RD&D Strategy

## Major System Requirements

<table>
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<tr>
<th>Req. No.</th>
<th>Description</th>
<th>Req.</th>
<th>Unit</th>
<th>Reference Requirements</th>
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<td>1.0</td>
<td>General</td>
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<td></td>
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<tr>
<td>1.1</td>
<td>120 GeV Beam Power</td>
<td>2.3</td>
<td>MW</td>
<td></td>
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<tr>
<td>1.2</td>
<td>8 GeV Beam Power</td>
<td>360</td>
<td>kW</td>
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<td>1.3</td>
<td>8 GeV Slow Spill Beam Power</td>
<td>200</td>
<td>kW</td>
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<td>1.4</td>
<td>8 GeV Slow Spill Duty Factor</td>
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<td>%</td>
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<td>1.5</td>
<td>120 GeV Availability</td>
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<td>1.6</td>
<td>8 GeV Availability</td>
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<td>%</td>
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<td>2.0</td>
<td>325 MHz Linac</td>
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<td>2.1</td>
<td>Average Beam Current</td>
<td>9</td>
<td>mA</td>
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<td>Pulse Length</td>
<td>1</td>
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<tr>
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<td>Repetition rate</td>
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<td>Hz</td>
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<tr>
<td>2.5</td>
<td>Peak RF Current</td>
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<td>mA</td>
<td>2.1 2.11 2.13 2.14</td>
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<td>Energy Variation (rms)</td>
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<td>2.9</td>
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<td>2.10</td>
<td>Transverse Emittance (95% normalized)</td>
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<td>2.11</td>
<td>Macro Bunch Duty Factor</td>
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<td>Micro Pulse Length</td>
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<td>2.14</td>
<td>Micro Pulse Period</td>
<td>11.1</td>
<td>μS</td>
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*etc...*
Project X RD&D Strategy
325 MHz Linac Issues

- No special accelerator physics issues are posed by a 420 MeV linac with this beam intensity.

- Development via the High Intensity Neutrino Source (HINS) program
  - 60 MeV front end demonstration based on scrf

- Technology choices
  - room temperature vs. superconducting
  - Upgrade path

- Beam duty cycle and machine availability requirements push the envelope of any existing H- ion source

- Superconducting triple-spoke accelerating cavity is outside the scope of the HINS program
Project X R&D Strategy
325 MHz Linac Technical Elements

- **FY08**
  - Basic accelerator physics design
  - HINS vs. alternative technology study
- **FY09**
  - Basic machine design and technology decisions completed
  - Begin
    - Ion source development,
    - Triple-spoke cavity electromagnetic and mechanical design,
    - Material procurement,
    - Low level RF development

- **FY10**
  - Ion source prototyping and testing
  - Triple-spoke prototype fabrication,
  - Vector modulator and RF distribution system development

- **FY11**
  - Fabrication triple-spoke cavities
  - Ion source development,
  - RF power distribution system design development
  - Beam instrumentation
  - Complete design
  - Complete cost estimates.

etc...
Disclaimer: This is not formally agreed to, although institutions have been invited to comment as this has been developed.

- Intention is to organize and execute the RD&D Program via a multi-institutional collaboration.
  - Goal is to give collaborators complete and contained sub-projects, meaning they hold responsibility for design, engineering, estimating, and potentially construction if/when Project X proceeds.
  - Project X RD&D Collaboration to be established via a Collaboration Memorandum of Understanding (MOU) outlining basic goals of the collaboration, and the means of organizing and executing the work.
  - It is anticipated that the Project X RD&D Program will be undertaken as a “national project with international participation”. Expectation is that the same structure of MOUs described above would establish the participation of international laboratories.
A draft MOU covering the period through CD-2 is currently circulating for comment among the management of the following potential U.S. collaborators:

- ANL
- BNL
- Cornell
- LBNL
- ORNL/SNS
- MSU
- TJNAF
- SLAC
Project X R&D Plan
Management Plan

• Fermilab responsible for management of the Project X RD&D program.
  – Program managed by a Project X RD&D Program Leader, assisted by a Program Team. Deliverables:
    ➢ reviewable/defensible accelerator physics and engineering design, cost estimate, and schedule to achieve CD-2/3a;
    ➢ including identification of possible upgrade paths;
    ➢ organization of a supporting R&D program.

• Collaboration Council established for the primary purpose of advising/assisting the Project Leader in inter-laboratory coordination.

• Project X Technical Advisory Committee.
  – Subcommittee to AAC?

• Fermilab 1.3 GHz program managed and coordinated jointly via the Assoc. Director for Accelerators and the ILC Program Director.
Project X RD&D Plan
Collaboration Plan

- Plan is to have an initial Collaboration Meeting, at Fermilab, in late summer/early fall with the following goals:
  - Form the RD&D Collaboration
    - Sign the Collaboration MOU;
    - Initial meeting of Collaboration Council
  - Agree to baseline performance goals and configuration
  - Establish/bless RD&D organization
  - Establish areas of responsibility and work plan for FY2009
Project X RD&D Plan
Budget Profile

<table>
<thead>
<tr>
<th>FY08</th>
<th>FY09</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
<th>TOTAL</th>
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<td>SWF</td>
<td>$6.7</td>
<td>$10.5</td>
<td>$19.1</td>
<td>$26.3</td>
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<td>M&amp;S</td>
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<tr>
<td>TOTAL</td>
<td>$8.1</td>
<td>$15.5</td>
<td>$25.4</td>
<td>$40.0</td>
<td>$88.9</td>
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Project X RD&D budget profile
- Scientists not included
- Can produce this table with any combination of scientists in or out, FY08 or AY$, burdened or unburdened
- Incremental to ILC, SRF, and HINS programs

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Project X RD&D Plan
Resource Requirements and Profile

Personnel profile by skills types
Note: This includes total resources, not just Fermilab; Incremental to ILC, SRF, and HINS programs
Project X RD&D Plan
Relationship to Other Programs: ILC/SRF

• Project X design concept aligns beam parameters with ILC:
  – 9 mA × 1 msec × 5 Hz
    ➢ Alternatives under consideration may provide enhanced performance and/or flexibility
  – Linac designed to accommodate accelerating gradients in the range 23.6 – 31.5 MV/m (XFEL – ILC)
    ➢ Final design gradient determined prior to CD-2

• Industrialization role
  – Project X requires 37 β=1, ILC-like cryomodules
  – Production over a two-to-three-year period represents a significant advance over capabilities anticipated in ~2010; however, the production rate is below that required by ILC
  ⇒ This activity would represent the initial phase of an industrialization buildup for ILC (in the U.S.).
Project X RD&D Plan
ILC/SRF Joint Development Strategy

- There is a single 1.3 GHz development program at Fermilab, supporting the ILC/GDE program and simultaneously understanding Project X requirements.

- At an appropriate time (before CD-2) the Project X cryomodule design will be developed.
  - The expectation is that it will be similar, but not identical, to the ILC design (including choice of gradient).
  - The design will be compatible with an identified upgrade path.

- Creation of facilities capable of fabricating one cryomodule/month remains the responsibility of the SRF infrastructure program.

- ILCTA-NML is being constructed under the SRF Infrastructure program to support beam testing of a complete rf unit.
  - This configuration supports substantial progress toward ILC (S1 and S2) goals: demonstration of stable high-power operations.
The HINS program is developing front end technology beyond the requirements of Project X initial goals:

- 60 MeV front end @ 27 mA × 1 msec × 10 Hz
- Demonstrate novel technologies for a high intensity non-relativistic linac
  - Multiple room temperature and sc cavities driven by a single rf source (high power vector modulators)
  - High speed (nsec) beam chopping at 2.5 MeV
- Establish technical feasibility and cost basis by ~2010
HINS Joint Development Strategy

- HINS provides a natural starting point for a Project X upgrade
  - $27 \text{ ma} \times 1 \text{ msec} \times 10 \text{ Hz} = 2 \text{ MW} \text{ (if accelerated to } 8 \text{ GeV})$
  - Other options: $9 \text{ ma} \times 3 \text{ msec} \times 10 \text{ Hz}$

- Two decisions (prior to CD-2):
  - Do we use HINS as the initial front end or do we utilize a conventional (room temperature) front end?
    - Cost-benefit analysis
  - Can we establish an $8 \text{ GeV}$ upgrade path via HINS and if so, how does this impact the $1.3 \text{ GHz}$ linac facility design?

- In either case it will be essential to carry the $60 \text{ MeV}$ facility through to completion
# Project X RD&D Plan

## Integrated SRF Plan

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<td>CM3</td>
<td>CM4</td>
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Project X RD&D Plan
Relationship to Other Programs: Muons

- Project X shares many features with the proton driver required for a Neutrino Factory or Muon Collider
  - Typically require 2-4 MW @ 10±5 GeV proton energy
  - Bunch packaging is much different → generally a small number of very intense bunches, with a repetition rate of ~50 Hz

- A natural evolution exists consisting of:
  
  Project X → Neutrino Factory → Muon Collider
Project X and the Muon Program
Possible Evolution (Palmer)

A Phased Approach

1. 8 GeV SC Linac
   PROJECT X

0. Recycler Main Injector
   EXISTING FACILITIES

2. Muon Collider R&D Hall
   Decoy Cool
   Target Phase Rot.
   & Bunch

3. Pre-Accel
   RLA (1-4 GeV)

4. 6D Cooling
   Final Cooling
   Muon Acc
   Collider Ring

5. More Acc
   Larger ring

1.5 TeV
MUON COLLIDER

4 TeV
MUON COLLIDER

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Project X RD&D Plan
Neutrino Factory Joint Development Strategy

• Develop upgrade concept for the Project X linac aimed at >2 MW (currently underway)
  - Integrate necessary requirements into the initial (360 kW) design

• Develop a performance specification for a Proton Driver supporting a Neutrino Factory and/or Muon Collider (APC), consistent with Project X concepts.
  - Issues: Average beam power, repetition rate, particles/bunch, bunch intensity

• Develop a conceptual design for the Proton Driver based on Project X linac and downstream accumulation/packaging ring(s).

• Coordinate with NFMCC, MCTF, IDS_NF

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Summary

- The Project X design concept supports a long term future for Fermilab based on world leading facilities at the:
  - Energy Frontier
  - Intensity Frontier

- Design concept exists for a facility with >2 MW beam power at 120 GeV, simultaneous with 200 kW at 8 GeV.
  - Major sub-system performance goals established
  - Supports world class program in neutrino physics and rare processes

- Design provides flexibility to support a long-term future for accelerator based physics at Fermilab
  - Potential upgrade paths to multi-MW at 8 GeV exist
  - Design aligned with needs of ILC technology development
  - Design concept supports future development of muon facilities
Summary

• Project X RD&D plan developed covering the period through CD2 (2011)
  – Integrates effort on Project X, ILC, and HINS
  – Resource plan exists
  – Team forming under the leadership of Dave McG.

• Working towards organizing as a national project with international participation.