Project X: A Multi-MW Proton Source at Fermilab

Steve Holmes
Fermilab Users’ Meeting
June 3, 2010
Outline

• Evolution of the Fermilab Complex
• Project X Goals and Initial Configuration(s)
• Project X R&D Program
• Relationships to other Programs
• Strategy

Project X website: http://www.fnal.gov/pub/projectx/
The Tevatron has now ceded the energy frontier to LHC

- Operations at 2 TeV will continue through September 2011

Fermilab operates the highest power long baseline neutrino beam in the world.

- J-PARC is initiating a competitive program
Fermilab is the sole remaining U.S. laboratory providing facilities in support of accelerator-based Elementary Particle Physics.

⇒ The Fermilab strategy is to mount a world-leading program at the intensity frontier, while using this program as a bridge to an energy frontier facility beyond LHC in the longer term.
Evolution of the Fermilab Accelerator Complex

• A multi-MW Proton Source, Project X, is the linchpin of Fermilab’s strategy for future development of the accelerator complex.

• Project X provides long term flexibility for achieving leadership on the intensity and energy frontiers

  – Intensity Frontier:
    \[ \text{NuMI} \rightarrow \text{NOvA} \rightarrow \text{LBNE/mu2e} \rightarrow \text{Project X} \rightarrow \text{Rare Processes} \rightarrow \text{NuFact} \]
    • Continuously evolving world leading program in neutrino and rare processes physics; opportunities for applications outside EPP

  – Energy Frontier:
    \[ \text{Tevatron} \rightarrow \text{ILC or Muon Collider} \]
    • Technology alignment
    • Fermilab as host site for ILC or MC
**Design Criteria**

- A neutrino beam for long baseline neutrino oscillation experiments
  - 2 MW proton source at 60-120 GeV

- High intensity, low energy protons for kaon and muon based precision experiments
  - Operations simultaneous with the neutrino program

- A path toward a muon source for a possible future Neutrino Factory and/or a Muon Collider
  - Requires upgrade potential to 2-4 MW at ~5-15 GeV.
• **Initial Configuration-1**

- 8 GeV H⁻ Linac
  - 20 mA x 1.25 msec x 2.5 Hz
- 8 GeV fast or slow spill
  - 4 x 10^{14} protons/1.4 sec
  - 360 kW
- 120 GeV fast extraction
  - 1.6 x 10^{14} protons/1.4 sec
  - 2.1 MW

- Stripping Foil
- Recycler
  - 1 Linac pulse/fill
- Main Injector
  - 1.4 sec cycle
- Single turn transfer at 8 GeV

• **Strong alignment with ILC technologies**

• **Initial Configuration Document-1 V1.1 released March 2009**
  - Accompanying cost estimate ~$1.5B
Initial Configuration - 1

Issues

• IC-1 does a great job of meeting the long baseline neutrino mission, but…

• does not provide a strong platform for mounting a low energy rare processes program
  – The Recycler is ill-suited to providing high intensity slow spilled beam
  – The Debuncher appears limited to $<150$ kW in this mode
    ⇒ We believe there is a fundamental limit on the amount of beam power that can be delivered via a resonant extraction system
  – Difficulties supporting multiple users with differing spill structure requirements

⇒ These considerations led to the development of IC-2
### Accelerator Requirements: Rare Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Proton Energy (kinetic)</th>
<th>Beam Power</th>
<th>Beam Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rare Muon decays</td>
<td>2-3 GeV</td>
<td>&gt;500 kW</td>
<td>1 kHz – 160 MHz</td>
</tr>
<tr>
<td>(g-2) measurement</td>
<td>8 GeV</td>
<td>20-50 kW</td>
<td>30- 100 Hz.</td>
</tr>
<tr>
<td>Rare Kaon decays</td>
<td>2.6 – 4 GeV</td>
<td>&gt;500 kW</td>
<td>20 – 160 MHz. (&lt;50 psec pings)</td>
</tr>
<tr>
<td>Precision $K^0$ studies</td>
<td>2.6 – 3 GeV</td>
<td>&gt; 100 mA (internal target)</td>
<td>20 – 160 MHz. (&lt;50 psec pings)</td>
</tr>
<tr>
<td>Neutron and exotic nuclei EDMs</td>
<td>1.5-2.5 GeV</td>
<td>&gt;500 kW</td>
<td>&gt; 100 Hz</td>
</tr>
</tbody>
</table>
• Initial Configuration-2

• 3 GeV CW linac provides greatly enhanced rare process program
  – 2-3 MW; flexible provision for beam requirements supporting multiple users
• Options for 3-8 GeV acceleration: RCS or (1.3 GHz) pulsed linac
  – Linac would be 1300 MHz with 4-5 msec pulse length
• Initial Configuration Document-2 in preparation for spring release
### Initial Configuration-2

#### Performance Goals

**Linac**
- **Particle Type**: H⁺
- **Beam Kinetic Energy**: 3.0 GeV
- **Average Beam Current**: 1 mA
- **Linac pulse rate**: CW
- **Beam Power**: 3000 kW
- **Beam Power to 3 GeV program**: 2870 kW

**RCS/Pulsed Linac**
- **Particle Type**: protons/H⁺
- **Beam Kinetic Energy**: 8.0 GeV
- **Pulse rate**: 10 Hz
- **Pulse Width**: 0.002/4.3 msec
- **Cycles to MI**: 6
- **Particles per cycle to MI**: $2.6 \times 10^{13}$
- **Beam Power to 8 GeV program**: 200 kW

**Main Injector/Recycler**
- **Beam Kinetic Energy (maximum)**: 120 GeV
- **Cycle time**: 1.4 sec
- **Particles per cycle**: $1.6 \times 10^{14}$
- **Beam Power at 120 GeV**: 2200 kW
Initial Configuration-2
Operating Scenario

1 μsec period at 3 GeV
- mu2e pulse (9e7) 162.5 MHz, 100 nsec 400 kW
- Kaon pulse (9e7) 27 MHz 800 kW
- Other pulse (9e7) 27 MHz 800 kW

Fermilab Users' Meeting, 2010 - S. Holmes
Initial Configuration-2
Provisional Siting
## Initial Configuration-2

### Technology Map

<table>
<thead>
<tr>
<th>Section</th>
<th>Freq (MHz)</th>
<th>Energy (MeV)</th>
<th>Cav/mag/CM</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSR0 $\beta_G=0.11$</td>
<td>325</td>
<td>2.5-10</td>
<td>26 /26/1</td>
<td>SSR, solenoid</td>
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<td>SSR1 $\beta_G=0.22$</td>
<td>325</td>
<td>10-32</td>
<td>18 /18/2</td>
<td>SSR, solenoid</td>
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<td>SSR2 $\beta_G=0.4$</td>
<td>325</td>
<td>32-160</td>
<td>33 /18/3</td>
<td>SSR, solenoid</td>
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<td>LB 650 $\beta_G=0.61$</td>
<td>650</td>
<td>160-520</td>
<td>42 /21/7</td>
<td>5-cell elliptical, doublet</td>
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<td>HB 650 $\beta_G=0.9$</td>
<td>650</td>
<td>520-2000</td>
<td>64 /8 /8</td>
<td>5-cell elliptical, doublet</td>
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<tr>
<td>ILC 1.3 $\beta_G=1.0$</td>
<td>1300</td>
<td>2000-3000</td>
<td>64 /8 /8</td>
<td>9-cell elliptical, quad</td>
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</tbody>
</table>
R&D Program
Choice of Cavity Parameters

• Identify maximum achievable surface (magnetic field) on basis of observed Q-slope “knee”

• Select cavity shape to maximize gradient (subject to physical constraints)

• Establish Q goal based on realistic extrapolation from current performance
  – Goal: <20 W/cavity

• Optimize within (G, Q, T) space

(Initial) Performance Goals

<table>
<thead>
<tr>
<th>Freq (MHz)</th>
<th>B_{pk} (mT)</th>
<th>G (MV/m)</th>
<th>Q</th>
<th>@T (K)</th>
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<tbody>
<tr>
<td>325</td>
<td>60</td>
<td>15</td>
<td>1.4E10</td>
<td>2</td>
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<tr>
<td>650</td>
<td>72</td>
<td>16</td>
<td>1.7E10</td>
<td>2</td>
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<tr>
<td>1300</td>
<td>72</td>
<td>15</td>
<td>1.5E10</td>
<td>2</td>
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</tbody>
</table>

HF Q-slope onset vs. Frequency (JLAB)
R&D Program
Choice of Cavity Parameters

SSR1:
325 MHz
$Q_0 = 1.4 \cdot 10^{10}$ @ 2K

ILC:
1.3 GHz
$Q_0 = 1.5 \cdot 10^{10}$ @ 2K

DESY data (last test) - status March 2009

72 mT
# Integrated SRF Plan
ILC + Project X

<table>
<thead>
<tr>
<th>U.S. Fiscal Year</th>
<th>2008</th>
<th>FY09</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
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<td><strong>1.3 GHz</strong></td>
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<td>CM1 (Type III+)</td>
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<td><strong>NML Beam</strong></td>
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<td>Single Cell Design &amp; Prototype</td>
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<td>SSR0/SSR2 Design &amp; Prototype</td>
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<td>SSR1 Cavities in Fabrication (14)</td>
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<td>CM325.1</td>
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<thead>
<tr>
<th>Process &amp; VTS/Dress &amp; HTS</th>
<th>Assemble</th>
<th>Install</th>
<th>Commission &amp; Operate</th>
<th>650 CM Ass’y</th>
<th>325 CM Ass’y</th>
<th>Operate Complete RF Unit @ Design Parameters</th>
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<tbody>
<tr>
<td>Design Procure</td>
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*Beam Available to RF Unit test except during installation periods (contingent upon cryogenic load/capacity)*
Integrated SRF Plan
ILC + Project X

NML test facility: ILC and Project X R&D
Project X

Joint PX/NF/MC Strategy

- Project X shares many features with the proton driver required for a Neutrino Factory or Muon Collider
  - NF and MC require ~4 MW @ 10± 5 GeV
  - Primary issues are related to beam “format”
    - NF wants proton beam on target consolidated in a few bunches; Muon Collider requires single bunch
  - Project X linac is not capable of delivering this format

⇒ It is inevitable that a new ring(s) will be required to produce the correct beam format for targeting.
Collaboration Plan

- A multi-institutional collaboration has been established to execute the Project X RD&D Program.
  - Organized as a “national project with international participation”.
  - Fermilab as lead laboratory
  - International participation via in-kind contributions, established through bi-lateral MOUs. (First MOU with India in place)
  - Collaboration MOU for the RD&D phase outlines basic goals, and the means of organizing and executing the work. Signatories:
    - ANL
    - ORNL/SNS
    - BARC/Mumbai
    - BNL
    - MSU
    - IUAC/Delhi
    - Cornell
    - TJNAF
    - RRCAT/Indore
    - Fermilab
    - SLAC
    - VECC/Kolkata
    - LBNL
    - ILC/ART
  - Collaborators to assume responsibility for components and sub-system design, development, cost estimating, and potentially construction.
• Next six months: Complete all preliminary design, configuration, and cost range information for IC-2
  – ICD-2v2.0
  – Cost estimate
• Continue conceptual development on outstanding technical questions
  – Baseline concept for the chopper
  – Concepts for marrying a 3-8 GeV pulsed linac to CW front end
  – Injection into RCS or Recycler
• Pursue R&D aimed at the CW linac
  – Emphasis of srf development at all relevant frequencies
  – Engage external collaborators and identify roles
• The DOE has advised that the earliest possible construction start is FY2015
  – We are receiving very significant R&D support for Project X and SRF development (~$35M in FY10, excluding ARRA)
• We believe that we could construct Project X over a five year time period, assuming a commensurate funding profile

⇒ Project X could be up and running ~2020
• Project X is central to Fermilab’s strategy for development of the accelerator complex over the coming decade
  – World leading programs in neutrinos and rare processes
  – Aligned with ILC and Muon Accelerators technology development;
  – Potential applications beyond elementary particle physics

• The design concept has evolved over the last year, providing significantly enhanced physics capabilities

• Current configuration:
  – >2 MW at 60-120 GeV, simultaneous with 3 MW at 3 GeV
  – Flexibility for supporting multiple experiments
  – CW linac is unique for this application, and offers capabilities that would be hard/impossible to duplicate in a synchrotron

• Project X could be constructed over the period ~2015 - 2019