FNAL Intense Proton Beam Strategy

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Fermilab

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Outline

• Near term neutrino strategy
• P5 recommendations
• Physics goals and requirements
• Long term strategy – High Intensity Proton Source
• Tactics – How to get there?
• Conclusions
Near Term Strategy

Fermilab currently operates the highest energy collider, and the highest power long baseline neutrino beam, in the world. In 2009:

- LHC will capture the energy frontier
- J-PARC will initiate a competitive neutrino program

To Soudan
MINOS at Soudan

2010 -2011
nu-bars, more nu running for for nue appearance

Next data publication
NuMI to NOvA
NOvA 14 kt & deep pit of building in “a” football stadium
(wire frame of loading dock in black hangs out over the stands by 30 yards)

Start data taking with full detector in 2013 with 6x10^{20} POT/year

Run 3 years neutrino and 3 years anti-neutrino

All goes well – significant data taking complete in 2019-2020
The Intensity Frontier

The accelerator-based neutrino program

- Measurements of the mass and other properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for understanding the evolution of the universe. The US can build on the unique capabilities and infrastructure at Fermilab, together with the proposed DUSEL, the Deep Underground Science and Engineering Laboratory proposed for the Homestake Mine, to develop a world-leading program in neutrino science. Such a program will require a multi-megawatt proton source at Fermilab.

- The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab.
Neutrino Program (cont)

- The panel recommends proceeding now with an R&D program to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL and recommends carrying out R&D on the technology for a large detector at DUSEL.

- Construction of these facilities could start within the period considered by this report.

- 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, if the science eventually requires a more powerful neutrino source. 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.
DOE OHEP proceeding to develop a conceptual design for an accelerator long-baseline neutrino experiment

Planning to get CD-0 approval by the end of CY 2008
- Fermilab will have overall project management
- Brookhaven will have responsibility for detector

Expectation is that detector will be located at DUSEL and the beam line at Fermilab.

Complete CD-1 by late 2009/early 2010.
- Explore alternatives for detector (technology, size, location)
- Explore alternatives for beamline (power, location)
- Cost/benefit analysis - scientific reaches, cost ranges, etc.

DOE OHEP & ONP collaborating with NSF
- On Detector R&D
- On development of a MOU for collaboration on nuclear and particle physics experiments.
- First Joint Oversight Group (JOG) meeting scheduled for Dec 10th
Intensity Frontier
Accelerator Based Neutrino Program

- DOE OHEP proceeding to develop a conceptual design for an accelerator long-baseline neutrino experiment
  - Planning to get CD-0 approval by the end of CY 2009
    - Fermilab will have overall project management
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  - Expectation is that detector will be located at DUSEL and the beam line at Fermilab.
    - Explore alternatives for detector (technology, size, location)
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    - Cost/benefit analysis - scientific reaches, cost ranges, etc.
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Dennis Kovar – November 2008 HEPAP Meeting
Long Baseline Neutrino Oscillations

The sensitivities shown on the following series of plots are from Mark Dierckxsen, U of C

CP : $P(\nu) = P(\nu\text{-bar})$?
\( \nu + \bar{\nu}, 100 \text{kt WCh} \)

18+18 \( 10^{20} \) PoT

- \( 3\sigma \) (\( \Delta m_{31}^2 > 0 \))
- \( 5\sigma \) (\( \Delta m_{31}^2 > 0 \))
- \( 3\sigma \) (\( \Delta m_{31}^2 < 0 \))
- \( 5\sigma \) (\( \Delta m_{31}^2 < 0 \))

Mass hierarchy sensitivity
With a 700KW beam, 6 years;
\( \sin^2 2\theta_{13} > 0.08 \) for all values of \( \delta \),
\( \sin^2 2\theta_{13} > 0.04 \) for 50% of \( \delta \)
$\nu + \bar{\nu}$, 300 kt WCh

60+60 $10^{20}$ PoT

Mass hierarchy sensitivity

with 3x mass and

3X POTs from 700 kW ;

$\sin^2 2\theta_{13} > 0.014$ for all values of $\delta$,

$\sin^2 2\theta_{13} > 0.01$ for 50% of $\delta$
$\nu + \bar{\nu}$, 300 kt WCh
60+60 $10^{20}$ PoT

$\delta_{cp}$

- $3\sigma$ ($\Delta m^2_{31} > 0$)
- $5\sigma$ ($\Delta m^2_{31} > 0$)
- $3\sigma$ ($\Delta m^2_{31} < 0$)
- $5\sigma$ ($\Delta m^2_{31} < 0$)

CP Sensitivity
With $\sim 2$ MW
Proton source,
6 years;
Want $\sin^2 2\theta_{13} > 0.01$
$\nu + \bar{\nu}$, 50kt LAr

120+120 $10^{20}$ PoT

$3\sigma$ ($\Delta m^2_{31} > 0$)

$5\sigma$

$3\sigma$ ($\Delta m^2_{31} < 0$)

$5\sigma$

Significant CP sensitivity if 12 years of data if we could deliver $20 \times 10^{20}$ POT/year

$\sin^2 2\theta_{13}$
What should we conclude?

- The metric we need to consider is effective mass $\times$ protons on target.
- Small mass (100kT WC) and low proton intensity (6x10^{20} protons/year) will have a significant improvement in sensitivity to the mass hierarchy over the NOvA experiment.
- For $\sin^2 2\theta_{13}$ at the 0.01 level, we will require a significant increase in effective detector mass and protons on target, to have good sensitivity in a CPV search.
World Wide Concepts for Large Detectors

**Water Cerenkov**

**Liquid Argon**

**Liquid Scintillator**

- **Hyper-Kamiokande**
- **FLARE**
- **LANND**

**DETECTOR LAYOUT**

- **Cavern**
  - Height: 115 m, diameter: 50 m
  - Shielding from cosmic rays: ~4,900 m.w.
- **Muon Veto**
  - Plastic scintillator panels (on top)
  - Water Cherenkov Detector
  - 1,500 phototubes
  - 100 m of water
  - Reduction of fast neutrino background
- **Steel Cylinder**
  - Height: 100 m, diameter: 30 m
  - 70 kℓ of organic liquid
  - 13,500 phototubes
- **Buffer**
  - Thickness: 2 m
  - Non-scintillating organic liquid
  - Shielding external radioactivity
- **Nylon Vessel**
  - Parking buffer liquid
    - From liquid scintillator
- **Target Volume**
  - Height: 100 m, diameter: 25 m
  - 50 kℓ of liquid scintillator
  - Vertical design is favorable in terms of rock pressure and buoyancy forces

**Present Tunnel**

**Future Safety Tunnel**

**Present Laboratory**

**Future Laboratory**

**with Water Cerenkov Detectors**

**Glacier**

**Electronic crates**

**δ ≈ 70 m**

**h = 20 m**

**Ponto insulation**

**LENAs**
Fermilab vision: The Intensity Frontier with Project X:

Great flexibility toward a very high power facility while simultaneously advancing energy-frontier accelerator technology.

- **NuMI (NOvA)**
- **DUSEL**
- **Main Injector:** 2.3 MW (120 GeV)
- **Recycler:** 200kW (8 GeV)
- **8 GeV ILC-like Linac**

*Project X* = 8 GeV ILC-like Linac + Recycler + Main Injector

*National Project with International Collaboration*
Plot courtesy: B. Zwaska

\[
POT(10^{20}) = \frac{1000 \times BeamPower(MW) \times T(10^7s)}{1.602 \times E_p(GeV)}
\]
A multi-MW Proton Source, Project X, is the linchpin of Fermilab’s strategy for future development of the accelerator complex.

Project X is designed to provide flexibility in evolving the Fermilab program in response to research results anticipated circa 2012.

- **Energy Frontier:**
  - **Tevatron** → ILC or Muon Collider
    - Technology alignment
    - Project X development retains ILC and MC as options for the Fermilab site

- **Intensity Frontier:**
  - **NuMI** → **NOvA** → LBNE/mu2e → multi-MW Proton Source → NuFact
    - Continuously evolving world leading program in neutrino physics and other beyond the standard model phenomena
Project X Design Criteria

- 2 MW of beam power over the range 60 – 120 GeV;
- Simultaneous with at least 150 kW of beam power at 8 GeV;
- Compatibility with future upgrades to 2-4 MW at 8 GeV

8 GeV $H^+$ Linac
20 mA x 1.25 msec x 2.5 Hz

8 GeV fast or slow spill
$4 \times 10^{14}$ protons/1.4 sec
360 kW

120 GeV fast extraction
$1.6 \times 10^{14}$ protons/1.4 sec
2.1 MW

Main Injector
1.4 sec cycle

Recycler
1 Linac pulse/flash

Stripping Foil

Single turn transfer
at 8 GeV
• Project X Design Criteria
  – 2 MW of beam power over the range 60 – 120 GeV;
  – Simultaneous with 2 MW beam power at 2 GeV;
  – Compatibility with future upgrades to 2-4 MW at 8 GeV
Project-X Research Program

• **A neutrino beam for long baseline neutrino oscillation experiments.** A new two or more megawatt proton source with proton energies between 50 and 120 GeV that would produce intense neutrino beams, directed toward a large detector located in a distant underground laboratory.

• **Kaon and muon based precision experiments driven by high intensity proton beams running simultaneously with the neutrino program.** These could include a world leading muon-to-electron conversion experiment and world leading rare kaon decay experiments.

• **A path toward a muon source for a possible future neutrino factory and, potentially, a muon-collider at the Energy Frontier.** This path requires that the new proton source have significant upgrade potential.
Near Term Strategy

• Project X is moving through the DOE system in coordination with the Long Baseline Neutrino Experiment (LBNE) and the muon to electron conversion experiment (Mu2e)
  – LBNE and Mu2e will both establish mission need (CD-0) on the basis of modest upgrades to the existing complex.
    ➢ Both have been told to expect CD-0 “shortly”, and to be prepared for CD-1 at the end of FY2010.
  – The Project X mission will be to provide significant extension of the reach of these two initiatives, while simultaneously creating a broader range of intensity frontier opportunities

• Several briefings for the Office of Science on strategy, including to Bill Brinkman by Pier Oddone on August 13

⇒ CD-0 for LBNE & Mu2e are pre-requisites to CD-0 for Project X
Department of Energy projects get approval through a Critical Decision Process (DOE Order 413.3)

- CD-0 : Mission Need
- CD-1 : Evaluation/Selection of Alternatives and Development of the Cost Range
- CD-2 : Project Cost, Schedule and Technical Baseline approved
- CD-3 Start of Construction
- CD-4 Start of Operations
LBNE

• DOE Project to construct a new Long Baseline Neutrino experiment

• CD-0 documentation has been prepared and is working its way through the system

• Goal is to reach CD-1 by end of 2010
  – Evaluation of alternatives: source, far site, technology,
    ....

  • Working model: Fermilab to DUSEL, water cerenkov (100 – 300 kT) and liquid argon (5 – 25 kT) detectors being designed

  • Cost estimates -> a cost range,

  • Preliminary schedule
Neutrino Beam Facility – Primary Beam

Primary beam ~ 1/6 of Main Injector
Beam Facility: Target Hall + Decay Pipe + Absorber + Near Hall
Far Detector Configurations

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<thead>
<tr>
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<th>kilotons</th>
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<tbody>
<tr>
<td></td>
<td>WC</td>
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<tr>
<td>Physics Equality</td>
<td>300</td>
</tr>
<tr>
<td>Physics Module</td>
<td>100</td>
</tr>
<tr>
<td>Total Module</td>
<td>120</td>
</tr>
<tr>
<td>Dimensions</td>
<td>~55m diameter, ~60m height</td>
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</table>

One can imagine 4 potential configurations

Can we optimize?
Equivalent categories of evaluation

<table>
<thead>
<tr>
<th>Target</th>
<th>Water</th>
<th>Liquid Argon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavern</td>
<td>upright cylinder, mailbox?</td>
<td>rectangular, soup can?, upright cylinder?</td>
</tr>
<tr>
<td>Primary Containment</td>
<td>Precast Concrete Liner, Poured Concrete?, Stainless Steel vessel?</td>
<td>insulated, non-evacuated Stainless Steel vessel, evacuable option(?)</td>
</tr>
<tr>
<td>Systems</td>
<td>water delivery, purification, temperature control, doping(?)</td>
<td>Cryogenic delivery, refrigeration, purification</td>
</tr>
<tr>
<td>Infrastructure Requirements</td>
<td>auxilliary rooms for systems</td>
<td>auxilliary rooms for systems, secondary containment, venting for ODH</td>
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<table>
<thead>
<tr>
<th>Target</th>
<th>Water</th>
<th>Liquid Argon</th>
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<tbody>
<tr>
<td>Active Detector</td>
<td>PMT's, light collectors, implosion protection, bases, HV, Cables(?)</td>
<td>TPC, HV, Cables, support structure; PMTs for triggering and timing</td>
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<tr>
<td>Electronics</td>
<td>preamps in/out? of H2O</td>
<td>pre-amps in liquid (cold)?</td>
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<tr>
<td>Calibration and Instrumentation</td>
<td>lasers, lamps, fibers, sources?</td>
<td>source?, purity monitors</td>
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<tr>
<td>Simulations</td>
<td>Neutrino Flux, Cross sections, Event Rates</td>
<td>rings, tracks</td>
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<tr>
<td>Reconstruction</td>
<td>rings</td>
<td>tracks</td>
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Need to determine the cost drivers and potential show stoppers

R. Rameika  June 2009 PAC 32
Major Issues

• Understanding cost and schedules for detector cavern construction and instrumentation
  – Parallel vs series construction

• Requirements for non-neutrino beam physics
  – Detector instrumentation – PMT coverage
  – Total mass!

• Does a mixed technology make sense?

• How can we make a case to justify/afford both technologies?
# Fermilab Ten-Year Plan at The Three Frontiers

(Technically Limited)

## Programs / Projects

### Energy Frontier

<table>
<thead>
<tr>
<th>Programs / Projects</th>
<th>FY08</th>
<th>FY09</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
<th>FY13</th>
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<td>LHC Upgrade Phase I</td>
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<td>LHC Upgrade Phase II</td>
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<td>Lepton Collider</td>
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### Intensity Frontier

- **MiniBooNE**
  - CD-3b
  - Conceptual Design
  - Design/Construction
  - Shutdown for NOvA

- **MINERvA**
  - CD-2
  - CD-3a/b
  - CD-0
  - CD-1
  - CD-2
  - CD-3a

- **MicroBooNE**
  - CD-4

- **NOvA**
  - CD-0
  - CD-1
  - CD-2
  - CD-3a

- **Long-Basedline 
  Project X**
  - CD-0
  - CD-1
  - CD-2
  - CD-3a

### Cosmic Frontier

- **Dark Matter**
  - CDMS (4 kg)
  - CDMS (15 kg)
  - CDMS (~1 ton) ?

- **COUPP (2 kg)**
  - COUPP (60 kg)
  - COUPP (~500 kg) ?

- **LAr (~1 ton)?**

- **SDSS**
  - CD-3b
  - DES

- **UHE Cosmic Rays**
  - Pierre Auger (South)
  - JDEM Science Operation Center

### Science and Technology Development Facilities

- **Detector**
  - Testbeam

- **Accelerator**
  - A0 Test Facility
  - SCRF Test Facility

- **Computation**
  - Lattice QCD

### Operation

### Construction

### R&D
Project X

Working Timeline

- FY2011
  - CD-1
- FY2013
  - CD-2/3a
- FY2014
  - CD-3: Initiate Construction
- ~FY2014~2018
  - Construct
Conclusions

• Fermilab has responsibility to carry out an aggressive conceptual design phase for a Long Baseline Neutrino Experiment (LBNE)
  – Awaiting CD-0 (DOE Mission Need)
  – Prerequisite to a CD-0 for Project X
  – Collaborative effort with BNL, LANL, Science Collaboration
  – Goal is CD-1 by end of 2010

• Very Massive Detectors are required to have significant discovery potential for the neutrino mass hierarchy and CP violation

• The 2 MW beam power from Project X is a necessity to carry out the Long Baseline experiment on a realistic time scale

Project X Physics Workshop : November 9-10

Followed by Muon Collider Physics Workshop : Nov. 10-12
http://www.fnal.gov/directorate/Longrange/Steering_Public/workshop-muoncollider.html
$\sin^2 2\theta_{13} > 0.06$ for all values of $\delta$,
$\sin^2 2\theta_{13} > 0.03$ for 50% of $\delta$
$\nu + \bar{\nu}$, 300 kt WCh

$30+30 \times 10^{20}$ PoT

- $3\sigma$ ($\Delta m^2_{31} > 0$)
- $5\sigma$ ($\Delta m^2_{31} > 0$)
- $3\sigma$ ($\Delta m^2_{31} < 0$)
- $5\sigma$ ($\Delta m^2_{31} < 0$)

Mass hierarchy sensitivity with $>2x$ POT and $3x$ mass;

$\sin^2 2\theta_{13} > 0.02$ for all values of $\delta$,

$\sin^2 2\theta_{13} > 0.012$ for 50% of $\delta$. 

$\delta_{cp}$ vs $\sin^2 2\theta_{13}$
\(\nu + \bar{\nu}, 50 \text{ kt LAr}\)

60+60 \(10^{20}\) PoT

\(\sin^2 2\theta_{13}\)

\(\delta_{\text{cp}}\)

\(\Line 3\sigma \ (\Delta m^2 > 0)\)

\(\Line 5\sigma \ (\Delta m^2 < 0)\)

\(\Line Potentially, some Greater reach with LAr\)
LAr5 @ DUSEL