Status of the NuMI Neutrino Beam at Fermilab

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Fermilab

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The NuMI Facility

- High-power neutrino beam for oscillation experiments
  - Beam tilted 3.3° down into the earth
- Neutrino beam travels to northern Minnesota
  - 735 km baseline
  - Intense source at Fermilab
  - Oscillated source in Minnesota
- Commissioned in 2004
- Operating since 2005

Near Detector: 980 tons  Far Detector: 5400 tons
Protons as Raw Material

- 120 GeV protons from the Main Injector
  - Designed for as many as $4 \times 10^{13}$ protons/pulse
  - 10 $\mu$s pulse every 1.9 s
  - 400 kW design power
- Shared proton capability
  - Antiproton Source
  - MiniBooNE beam
- Possibility to increase power in future
  - Redirect MiniBooNE protons
  - Re-use antiproton machines
The NuMI Beam

“Neutrinos at the Main Injector”
The NuMI Beam

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- 400 kW design average power
- $\sigma \sim 1$ mm
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- 2 interaction length, C target
- Produces $\pi^+$, $K^+$ mesons

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- Target
  - 120 GeV protons
  - From Main Injector

- Target Hall
  - #1 Horns
  - #2 Horns
  - Decay Pipe
  - $\pi^+$
  - $\mu^+$
  - Hadron Monitor
  - 10 m
  - 30 m
  - 675 m

- Absorber

- Muon Monitors
  - $\nu_{\mu}$
  - 12 m
  - 18 m
  - 210 m

- Rock

- Pulsed focusing horns
- Toroidal magnetic field
- Parabolic inner conductor profile
- Focuses meson momentum band

- 400 kW design average power
- $\sigma \sim 1 \text{ mm}$
The NuMI Beam

“Neutrinos at the Main Injector”

- 2 m diameter
- Roughly decay length for 10 GeV $\pi^+$
- Evacuated & cooled

Target

120 GeV protons

From Main Injector

10 m 30 m

Target Hall

Decay Pipe

Absorber

Muon Monitors

Hadron Monitor

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“Neutrinos at the Main Injector”

- Absorbs 160 kW of protons and other hadrons
- Allows high-energy muons to penetrate

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120 GeV protons from Main Injector

Target Hall

Decay Pipe

Muon Monitors

Absorber

Hadron Monitor

- 2 m diameter
- Roughly decay length for 10 GeV
- Produces π⁺, K⁺ mesons
- 2 interaction length, C target, Evacuated & cooled
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- σ ~ 1 mm
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The NuMI Beam

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- Measure hadron & muon fluxes
- Arrays measure distributions
Variable Energy Neutrino Beam

Low Energy Beam

Proton $\rightarrow$ Target $\rightarrow$ Horn 1 $\rightarrow$ Horn 2

Pions with $p_T = 300$ MeV/c and $\begin{cases} p = 5 \text{ GeV/c} \\ p = 10 \text{ GeV/c} \\ p = 20 \text{ GeV/c} \end{cases}$

Figure courtesy Ž. Pavlović
Variable Energy Neutrino Beam

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High Energy Beam

figure courtesy Ž. Pavlović
Variable Energy Neutrino Beam

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Vary the beam energy by sliding the target in/out of the 1st horn.

High Energy Beam

Proton \rightarrow \text{Target} \rightarrow \text{Horn 1} \rightarrow \text{Horn 2}

Figure courtesy Ž. Pavlović
Variable Energy Neutrino Beam

Low Energy Beam

Proton \rightarrow Target \rightarrow Horn 1

Horn 2

MINOS Data

Pions with

\begin{align*}
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\end{align*}

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High Energy Beam

Proton \rightarrow Target \rightarrow Horn 1

Horn 2

\text{figure courtesy Ž. Pavlović}
Achieving a Precision $\nu$ Spectrum

- Component placement affects the $\nu$ beam
  - Beam monitors detect changes in muon & hadron beams
  - Variation measured spill-to-spill

- Beam based alignment for all major components

- Horn 1 displacements affect pion focusing
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![Diagram of beam path and components](image)
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![Diagram showing pion focusing and misalignment effects](image)

**Horn 1 Misalignment**
- $1\text{mm}$ offset
- $2\text{mm}$ offset
- $3\text{mm}$ offset
- $4\text{mm}$ offset

![](chart)

**Energy (GeV)**

$ND(\text{offset})/ND(\text{nominal})$
Beam Performance

- Typical beam powers of 180 kW
  - Higher beam powers of ~ 270 kW without antiproton production
- Downtimes due to:
  - Planned shutdowns
  - Component failures
  - Accelerator downtime
Reliability

- Major points of failures are the secondary beam components
  - **Target**
    - First had a water leak repaired, then motion failed
    - Now on second target
  - **Horns**
    - Each has had repairs
- Significant impact upon delivered number of protons
- Inventory of spares in progress
- Repair capability invented, now being augmented
New Beam Records

- 11 batch slip stacking produces $> 4 \times 10^{13}$ protons
  - Exceeds target design intensity
  - Changing to a larger spot size
- Beam power has reached 325 kW
  - Plan to be able to exceed 400 kW for short periods of time
- Expect to integrate $\geq 50\%$ more protons in 2008
  - Requires improvement in loss control in MI and reliability in NuMI
Users

- MINOS – Main Injector Neutrino Oscillation Search
  - Primary user – built concurrently with NuMI
  - 10s of millions of neutrino events
  - Producing world-competitive measurements
  - 10s of millions if neutrinos

- MINERvA experiment starting construction
  - Sited in MINOS Fermilab hall

- NOvA experiment proposed and in planning
  - New detector in northern Minnesota
  - Includes beam upgrades to 700 kW
Conclusion

• The NuMI beam has been in operation over 2 years
  ➢ Beam power is below design, but consistent with expectations
  ➢ Continuing to see improvement via Proton Plan

• Reliability improved for high-power components
  ➢ Had been a significant cost in beam throughput

• Precision beam information used for experiments
  ➢ Car in design and measurement of beam components
  ➢ Verification through monitoring
  ➢ Checked with millions of neutrinos by MINOS
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Secondary Beam Monitoring

- Spill-to-spill measurements of the Neutrino beam (faster than Near Detector)
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Beam-Based Alignment

- Proton beam scanned horizontally across target and protection baffle
  - Also used to locate horns
- Hadron Monitor and the Muon Monitors used to find the edges
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- Proton beam scanned horizontally across target and protection baffle
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  - Measured small (~1.2 mm) offset of target relative to primary beam instrumentation.