Initial Performance from the NOvA Surface Prototype Detector

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The NOvA Experiment

• Long baseline neutrino oscillation experiment:
  o Near and far detector pair.
  o Off-axis $\nu @ L/E \sim 400 \text{ km/GeV}$

• Goals:
  o Search for $\nu_\mu \rightarrow \nu_e$ transitions
  o measure/limit $\theta_{13}$
  o determine mass hierarchy
  o constrain CP violating phase
  o precision measurements of $|\Delta m^2|$, $\theta_{23}$
  o compare $\nu/\bar{\nu}$ oscillations
Design Criteria

- Experimental Sensitivity: Order of magnitude improvement in $\theta_{13}$ limit.
- Energy resolution for $\nu_e$ Charged Current events: Less than 8% at 2 GeV
- Energy resolution for Quasi-Elastic $\nu_\mu$ Charged Current events: Less than 4% at 2 GeV

3 $\sigma$ Sensitivity to $\sin^2(2\theta_{13}) \neq 0$

$L = 810$ km, 15 kT
$\Delta m^2 = 2.4 \times 10^{-3}$ eV$^2$
$\sin^2(2\theta_{23}) = 1$

3 years at 700 kW, 1.2 MW, and 2.3 MW for each $\nu$ and $\bar{\nu}$

$\Delta m^2 > 0$
$\Delta m^2 < 0$
Off-Axis Beam

- At 14 mrad off-axis, narrow band beam peaked at 2 GeV
  - Near oscillation maximum
  - Few high energy NC background events
The NOvA Detectors

- Near Detector:
  - 220 tons, 1 km from NuMI
  - 105 m underground
- Far Detector:
  - 14 kton, 810 km baseline
  - Overburden >10 rad. Length
- Common Technology:
  - Reduced systematics
  - Low Z; 65% Active Volume
  - Operational surface prototype near detector (NDOS)
Beam Upgrade to 700 kW:
• Accelerator shutdown: March 2012

Far Detector:
• Construction: Jan 2012
• 1 block by shutdown start
• 50% by end of shutdown
• Complete by early 2014

Near Detector:
• Cavern excavation during shutdown
• NDOS: Running now!!
Near Detector on the Surface

• Full size prototype Near Detector constructed and assembled to mimic far detectors operations as closely as possible.

• Collecting data since October 2010
• Virtually all detector subsystems have benefited as we move closer to Far Detector. (Highlighting the major ones here.)
Near Detector On the Surface

- 6 blocks of 31 alternating orthogonal planes and the MC are installed and filled with scintillator.
- ~75% of the detector is instrumented with electronics.
- Gets triggers (500 μs wide) from NUMI and Booster, plus 10 Hz pulser.
- No overburden.
- We are in the process commissioning this detector.
**NOvA Cell**

- **NOvA cell:**
  - 3.8 cm X 5.9 cm X 15.5 m; ~4 mm thick
  - Titanium dioxide loaded PVC (~90% reflectivity at 430 nm)
  - 8 reflections on average
  - 0.15 radiation length per layer filled
  - ~385,000 for 15 kTon. 32 in a sealed module.

- **NDOS:** Experience in QA/QC. Leaning how to ship, handle, repair. (~20% of delivered manifold covers cracked.) Fed back into design for production pieces. (Add’l talk)
Liquid Scintillator

- 70% of detector mass
- Mineral oil with 5% pseudocumumene and wavelength shifters producing light at 400 – 450 nm
- Light in a NOvA cell is captured locally by a wavelength-shifting fiber within about one meter at less than 80% attenuation.
- 3.9 million gallons of liquid scintillator at far site.

• NDOS: Experience qualifying scintillator. Refined filling procedure for record keeping and cleanliness. Found internal obstructions preventing complete fills.
Fibers

- Single sided readout from 0.7 mm diameter looped fiber
- Shifts light to green 490 - 550 nm.
- Light is attenuated by about a factor of ten with red light (520 – 550 nm) preferentially surviving.
- 13,000 kilometers of wavelength shifting fiber for far detector.
- NDOS: Experience in stringing modules. Reworked spooling techniques to minimize tangles. Experience with in-module QA.
APD (Avalanche Photo Diode)

- 85% QE for 520 – 550 nm light.
- Gain of 100 @ 375 volts.
- Actively cooled to -15 C.
- Signals pass through low-noise on-board amplified
- Require 20 pe signal from MIP at far end of cell with 10-15 pe threshold. (We expect 38 pe.)
- ~12,000 APDs on FEBs
- NDOS: Cleanliness issues during installation led to noisy channels. New surface coating under-investigation.
• Front-end electronics operate in continuous digitization mode.
• Data from the ADC is processed on-board with correlated sampling.
• 64 FEBs feed a Data Concentrator Module which passes the data to a processing farm.
• Data is buffered until the arrival of a software spill trigger.
• Data rate driven by cosmic ray muons (0.5 GB/s) (Mimicked at NDOS).
• NDOS: Since deployment updates to the software have doubled real throughput.
NDOS
Early Analysis from Actual Neutrinos

Simulated Neutrino Events

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Early Analysis from Actual Neutrinos

- 5.6x10^{19} POT reverse horn current beam, 1001 NuMI events (69 cosmic BG)
- 8.4x10^{18} POT forward horn current beam, 253 NuMI events (39 cosmic BG)
- 3x10^{19} POT, 222 booster events (92 cosmic BG)
Commissioning/Calibration Experience

- Cosmic muons provide intra-detector calibration source

- Early look at contained events indicates NuMI MC event rate agrees with data

- Use Michel electrons for electro-magnetic energy calibration
Conclusions

• The NOvA NDOS is taking data now and has been vital to the overall program.
• We are learning a lot about our detector as we prepare for the far and near detector construction.
• NOvA offers broad and impactful physics program that is still in early but exciting stages.

... Stay Tuned!
Additional Speakers

For more details please attend these sessions:

**Detector for Neutrinos** - June 11, 14:00; Superior A
- Sarah Phan-Budd, NOvA PVC Extrusions
- Alex Smith, NOvA Module QC/QA

**Trigger and DAQ Systems** - June 11, 16:00; Mayfair
- Susan Kasahara, NOvA Data Acquisition Systems and Software
\[
\begin{bmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau \\
\end{bmatrix} = U^\dagger \begin{bmatrix}
\nu_1 \\
\nu_2 \\
\nu_3 \\
\end{bmatrix}
\]

- Flavor States: creation and detection
- Mass States: propagation

\[
P(\nu_\alpha \rightarrow \nu_\beta) = \left| \sum_j U^*_\beta_j e^{-i\frac{m_j^2 L}{2E}} U_{\alpha j} \right|^2
\]

Oscillation probability depends on: dist. traveled (L), \( \nu \) energy (E), and difference in the squared masses \( \Delta m^2_{ij} = m_i^2 - m_j^2 \).
Actual Neutrino Events

NOvA - FNAL E929
Run: 11956/6
Event: 273516
UTC Mon Apr 11, 2011 00:35:22.853571392

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