Background and Introduction

- Neutrinos are neutral leptons that interact via the electroweak force.
- Neutrinos come in three flavor eigenstates: \( \nu_e, \nu_\mu, \nu_\tau \). These states are linear combinations of mass eigenstates, denoted \( \nu_1, \nu_2, \nu_3 \). Observations of oscillations between flavor states have been made.
- Mixing angles are the measurable parameters that govern how neutrinos oscillate. They are provided here in the Pontecorvo–Maki–Nakagawa– Sakata (PMNS) matrix:

\[
\begin{pmatrix}
0 & \cos \theta_{12} & \cos \theta_{13} \\
\sin \theta_{12} & 0 & -\sin \theta_{13} \\
0 & \sin \theta_{13} & 0
\end{pmatrix}
\]

- NOvA (NUMI Off-Axis \( \nu_e \) Appearance) is a neutrino detection experiment with two detectors, both located 14 mrad off axis with respect to the NUMI beam:
  - The near detector is located at Fermi National Accelerator Laboratory (FNAL), the origin of the \( \nu_e \) beam.
  - The far detector is located 810 km away from FNAL.

- The camera is a qualitative check for low contrast images.

Far detector

- Cross-test analysis between the SFT and the CFT was performed to search for correlations between the tests:
  - A slight positive correlation is observed between the two tests, as indicated by a positive \( \chi^2 \) statistic.
  - The results are expected because they are both measuring the same thing, relative transmitted light loss.
  - Results suggest that the wavelength of light used to perform the test (blue LED used in SFT vs. red LED used in CFT) is independent of the test's outcome.

Module Construction, Stringing and Test Performance

- Far detector comprises ~11,000 individual modules made of PVC and filled with liquid scintillator.
- Light is emitted by scintillating liquid excited by charged particles traveling through it.
- Wavelength shifting fibers transmit light to the Avalanche Photodiodes (APDs).
- Fiber QA tests are in place to check for damaged fibers:
  - The stringing fiber test (SFT) looks for damage during stringing using a blue LED to measure relative intensity of transmitted light.
  - The closed fiber test (CF T) uses a red LED to measure transmitted light after sealing the module.
  - The visual test is a qualitative check for low-transmitting fibers.
  - The visual card test is a qualitative check for high-reflecting fibers.

Test Results and Analysis

- The effects of tension during stringing were analyzed to search for a potential source of damage:
  - Relative light intensity from the SFT is a ratio of light intensities calculated by dividing the final measurement (32 m of fiber) by the initial measurement (0 m of fiber). Measurements are taken continuously.
  - Over-tension alarms are triggered when a maximum tension greater than 3 Newtons is reached. Those cells are restrung and not included here.
  - The plots indicate that high tension, under the alarm value, does not damage fiber.

- Once the CFT and SFT were correlated, further analysis was performed on CFT to verify that tension had no effect on light attenuation:
  - Histogram has slight tail with negative slope but otherwise looks flat.
  - Indicative of stringing at high tensions under 3 N does not do significant damage to fibers.
  - Similarities to fig. 3 suffice as further evidence to suggest tests are correlated.

Future Work

- Analyses on these as well as other tests continues.
- The camera test will be implemented in the near future acting as a quantitative supplement to the visual and visual card tests.
- The module factory is currently at full production and the first module was installed at Ash River on August 1, 2012. The detector is expected to begin taking data in 2013 and the first run will last six years.

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