Alignment of the NOvA Detectors

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On behalf of the NOvA collaboration

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The NOvA Experiment

- Long-baseline neutrino experiment investigating the appearance of $\nu_e$ and disappearance of $\nu_\mu$ from the NuMI beamline at Fermilab.

- Two functionally identical detectors located 810 km apart.

- These sit 14.6 mrad off-axis, yielding a narrow neutrino energy band around the 2 GeV oscillation maximum.
Physics Goals

The experiment intends to:

- Make precision measurements of neutrino oscillation parameters $\theta_{23}$ and $\Delta m^2_{32}$ and determine the octant of $\theta_{23}$.
- Determine the neutrino mass hierarchy.
- Search for exotic particles (e.g. sterile neutrinos).

$$P_{\mu \to \mu} \approx 1 - \sin^2 2\theta_{23} \sin^2 \left( \frac{\Delta m^2_{32} L}{2E} \right)$$
The NOvA Detectors

- Functionally identical fine-grained **tracking calorimeters** consisting of extruded plastic cells filled with **liquid scintillator**.
- Far Detector: 344,064 readout channels
- Near Detector: 20,192 readout channels
Detector Alignment

- Each 'pixel' of the detector is a cell. These are put together to form planes, each of which features 384 cells.

- 32 of these planes form a block of which there are 28 in the far detector.

- The most significant misalignment of detector elements is on a block level – thus procedures are under development to align on a block-to-block basis.

The motivation for doing so:

- To reduce systematic uncertainties related to detector calibration.
- Improve main NOvA analyses through 2nd order effects (e.g. particle ID).
Cosmic Ray Muon Tracks

- Cosmic ray muon tracks used for the alignment procedure.
- The Far Detector is located on the surface.
- It sees ~50-70 cosmic rays in each 550 µs trigger window.

Cuts applied to cosmic tracks:

- At least **1000 cm** in length.
- Pass through at least **4 blocks**.
- Angular cut of **30° relative to the z-axis**.
- Containment and quality cuts.
Block Residual Analysis

- Two methods by which to determine block-level misalignments using cosmic ray muons have been developed.

- The first method **fits simple straight lines** to muon tracks, **excluding** hits from the block for which misalignment is being determined.

- The removed hits are compared with the fitted line to calculate **residuals** $\Delta x$ and $\Delta y$.

- Mean $x$ and $y$ residuals for each block are minimised through the introduction of shifts and the analysis is **repeated iteratively** to decouple block misalignments.
Blocks Residual Analysis

NOvA Preliminary

Pre-iteration results

- Iterations are performed until a point is reached where any shift applied to a block by the procedure is minimal (< 0.1 cm).

- In this way a general set of $\Delta x$ and $\Delta y$ for each block are acquired.
• Iterations are performed until a point is reached where any shift applied to a block by the procedure is minimal ($< 0.1 \text{ cm}$).

• In this way a general set of $\Delta x$ and $\Delta y$ for each block are acquired.
Tilting and Rotations

- In a similar fashion tilting in the blocks can be determined by looking into the residuals as functions of x and y.
- The angle of this tilt can be determined to acquire a general set of $\Delta \theta$ and $\Delta \phi$ rotations for each block.

Tilt of $\sim 0.04^\circ$ in block 15
• The second analysis method serves as an **independent cross-check** to the first.

• Muon track hits are divided up into the respective blocks they traverse and separate fits are performed on **track segments** either side of block boundaries.

• $\Delta x$ and $\Delta y$ are calculated by **interpolating** each of the fits to the block boundary and comparing the two.
Track Segment Analysis MC Study

- **Known shifts** (shown in white) **added to blocks** in a Cosmic Ray Shower Generator (CRY) Monte Carlo simulation with otherwise perfect detector geometry.

- The track segment analysis manages to successfully determine the misalignments introduced to the blocks.
Conclusions

• Two methods by which block-level misalignments in the NOvA detectors can be determined have been developed.

• Both analysis methods show promise in both data and MC studies.

• A general set of $\Delta x$ and $\Delta y$ block shifts (and $\Delta \theta$, $\Delta \varphi$ rotations) are to be acquired and incorporated into the NOvA detector geometry simulation.