

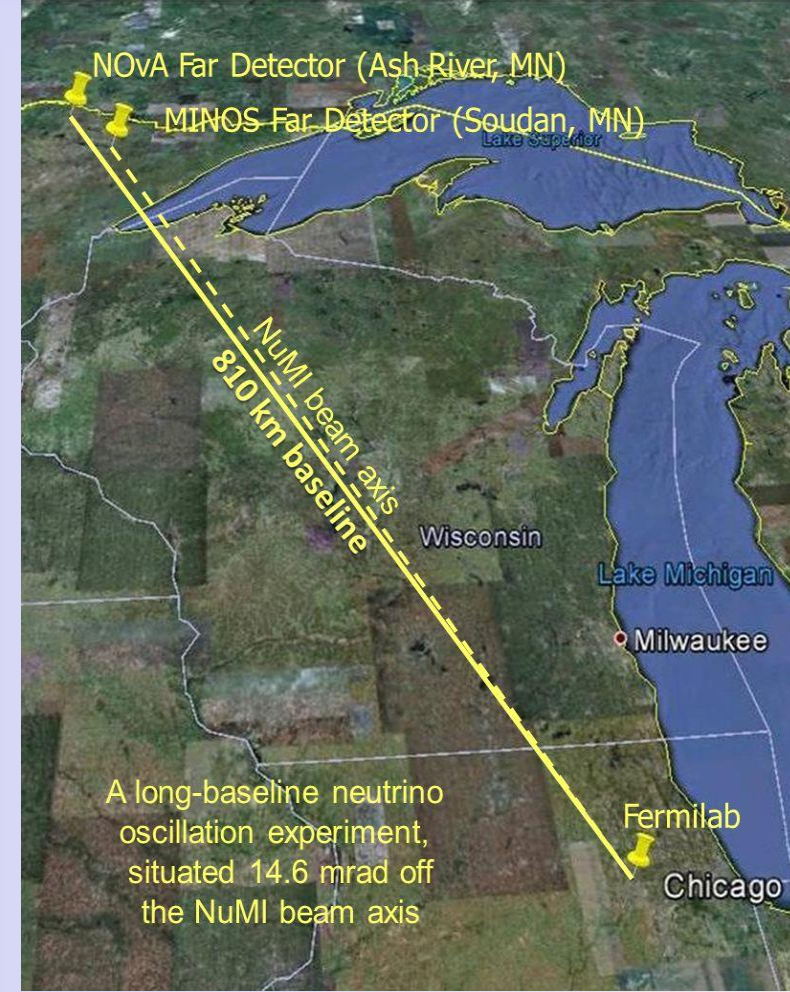
Survey of the Fermilab NOvA Detectors

Babatunde O'Sheg Oshinowo and Horst Friedsam
Fermi National Accelerator Laboratory, Batavia, Illinois, U.S.A.



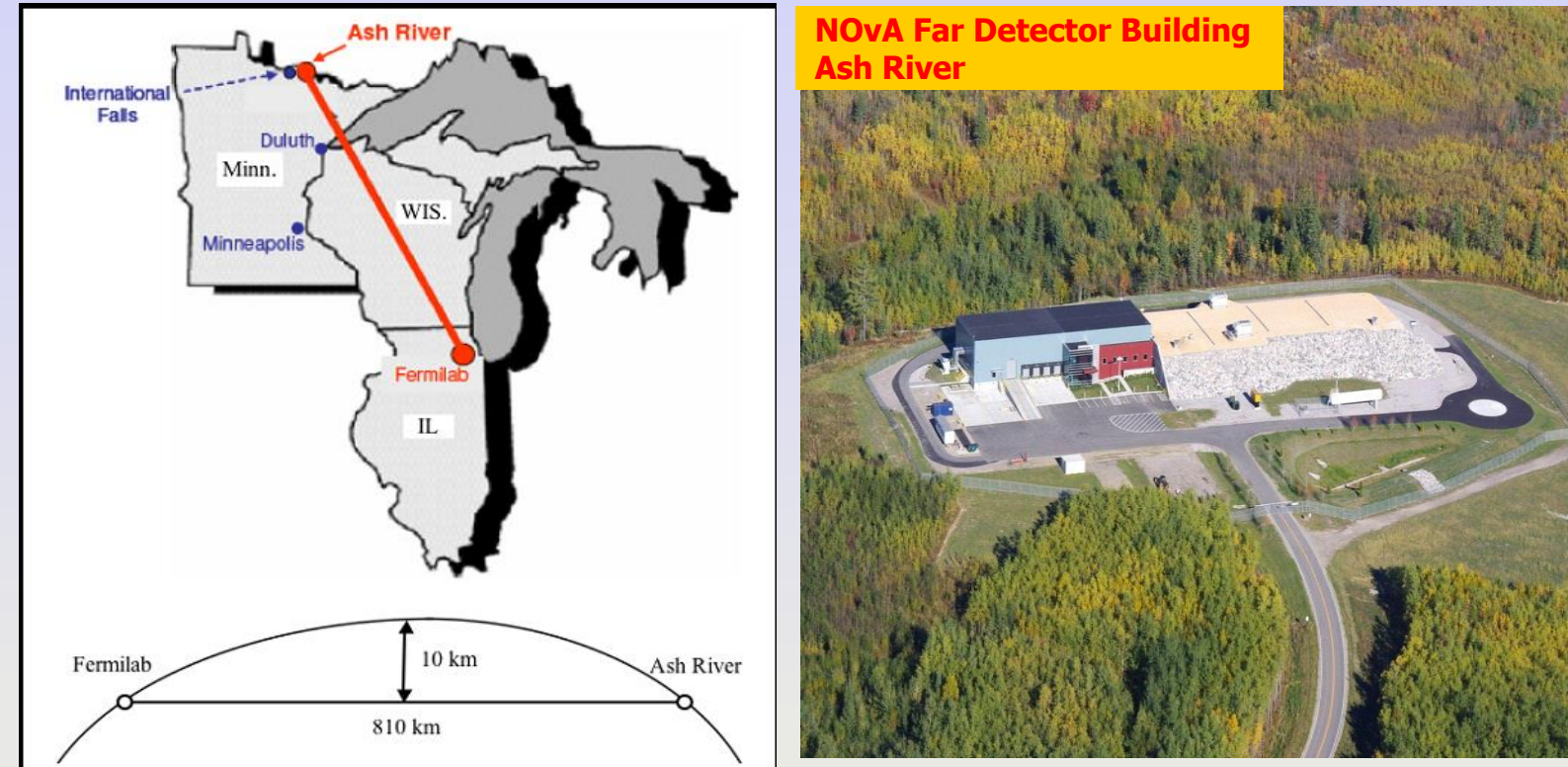
The NOvA Experiment

NOvA: NuMI Off-Axis ν_e Appearance Experiment
 $\nu_e =$ electron neutrino



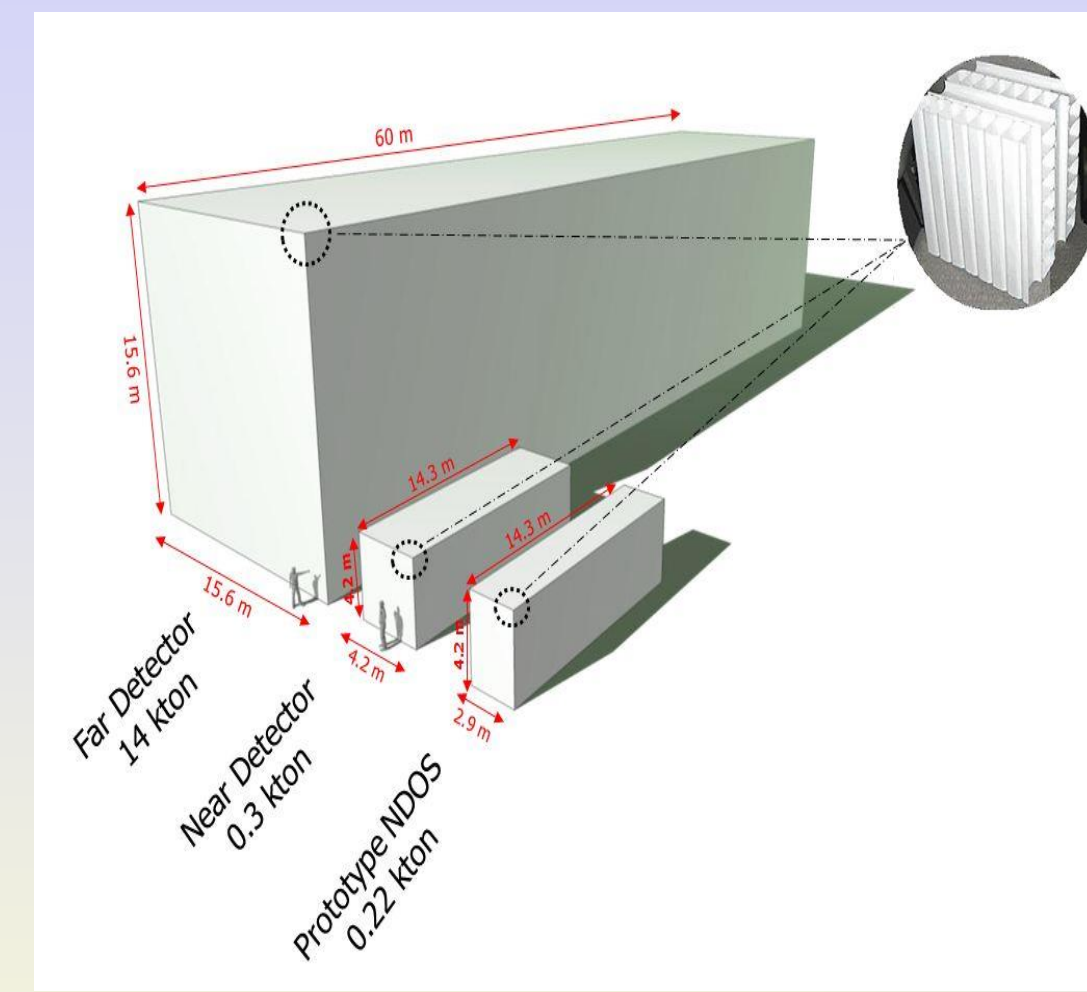
- North America's most advanced neutrino experiment
- The NOvA project includes accelerator upgrades to bring the NuMI (Neutrino at Main Injector) beam intensity from 400 kW to 700 kW
- Uses two detectors to look for changes in the neutrino beam as it travels:
 - Far Detector** in Ash River, Minnesota
 - Near Detector** at Fermilab
- The NOvA detectors are sited 14.6 mrad off the center of the NuMI beam axis
- Mostly active liquid scintillator Near and Far Detectors and PVC plastic
- Full operation began in October 2014
- Scheduled to Run at least till 2021

Far Detector Site



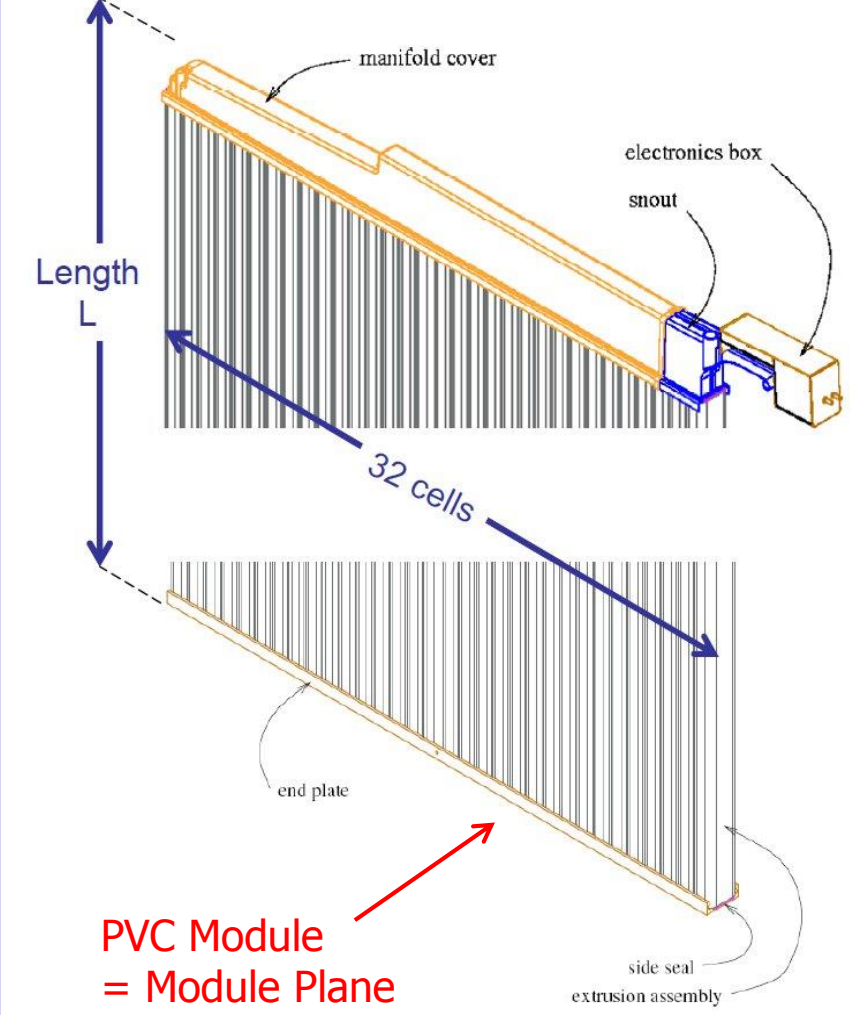
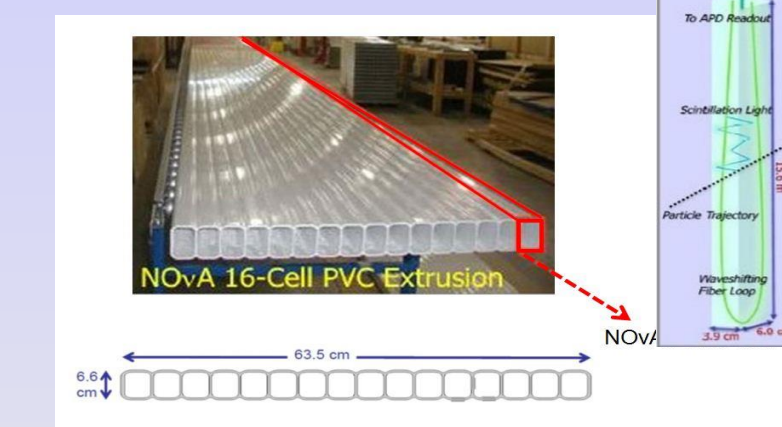
- This site is at 810 km from Fermilab, about 11.8 km off-axis from NuMI beam
- The Ash River site, near Canadian border, is the farthest available site from Fermilab in the U.S. along the NuMI beamline

NOvA Detectors



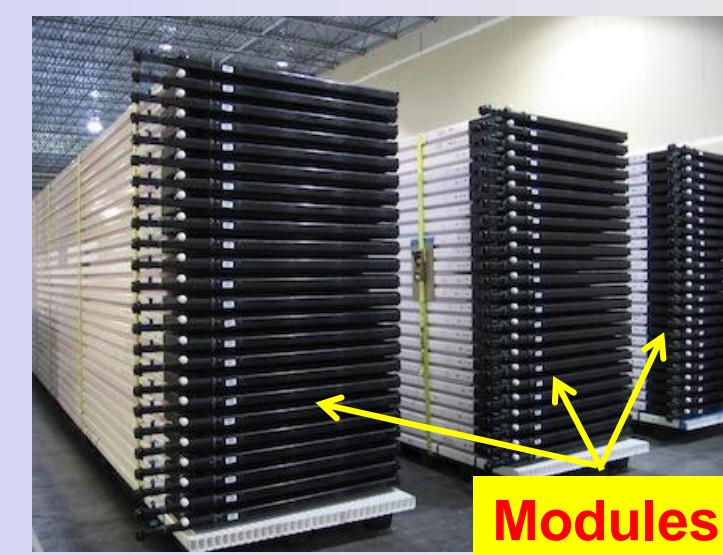
- A 14 kton Far Detector at a distance of 810 km from the NuMI Target (Completed at Ash River in July 2014)
- A 0.33 kton Near Detector identical to the Far Detector at a distance of 1 km from the NuMI Target (Completed at Fermilab in February 2014)
- An 0.22 kton prototype NDOS (Near Detector On the Surface) identical to the Near Detector sited on the surface 107 mrad off the NuMI beam axis at Fermilab (Completed in 2010 and operated till January 2013)

NOvA Detector Module



- NOvA detectors are constructed from planes of PVC modules
- Extrusions have a cellular structure, with 16 isolated cells per extrusion
- A module of 32 cells is constructed from two 16-cell PVC extrusions glued together
L = 15.6 m for Far Detector
L = 4.2 m for Near Detector
- Each cell contains liquid scintillator and light measuring fiber optics
- Modules are capped by a Manifold and an End Cap to contain the liquid volume

NOvA Detector Module



- NOvA Detector is constructed from alternating planes of vertical and horizontal PVC extrusion modules, connected together by glue between planes
- 12 extrusion modules are glued together side by side on a flat assembly table to form one plane (or layer) of the Far Detector
- 3 extrusion modules are glued together for the Near Detector

NOvA Near Detector Block

- 24 planes make 1 NOvA **block** for Near Detector
- NOvA Near Detector block (**B**) configuration is as follows:

$$B = h_0 v_1 h_2 v_3 h_4 v_5 h_6 v_7 h_8 v_9 h_{10} v_{11} h_{12} v_{13} h_{14} v_{15} h_{16} v_{17} h_{18} v_{19} h_{20} v_{21} h_{22} v_{23}$$

where **v** are vertical planes and **h** are horizontal planes of modules; number of planes is counted from 0 through 23

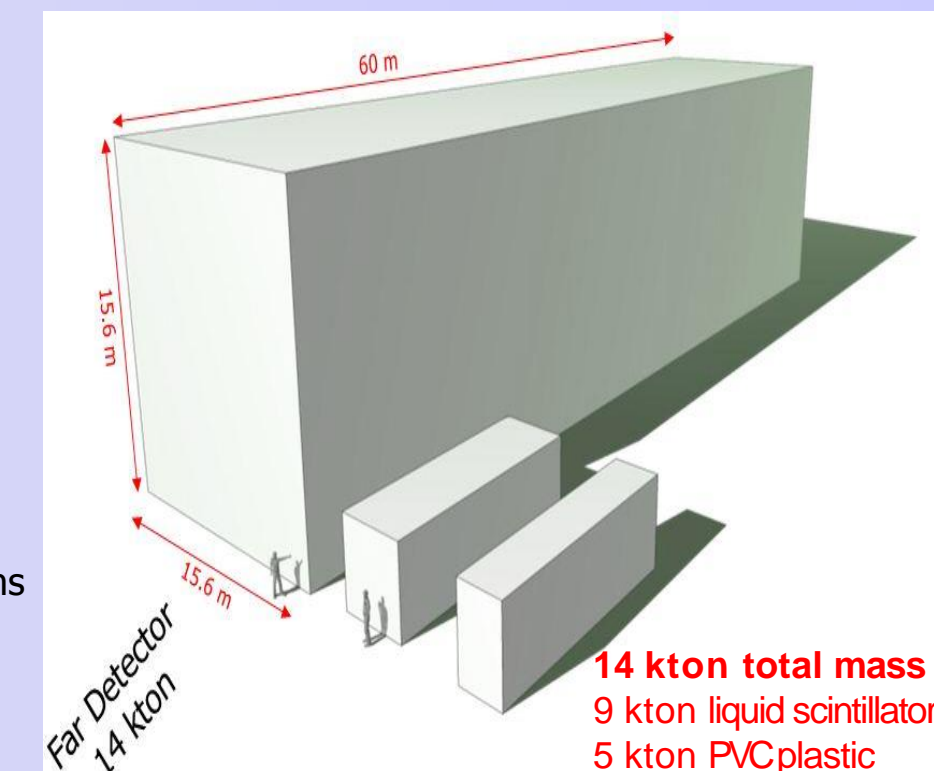
- Block assembly starts from plane-23 (**v₂₃**) on the assembly table and ends with plane-0 (**h₀**)
- All planes in each block are glued together in a horizontal orientation on a block assembly table

NOvA Far Detector Block

- 32 planes make 1 NOvA **block** for Far Detector
 - NOvA Far Detector block (**B**) configuration is as follows:
- $$B = h_0 v_1 h_2 v_3 h_4 v_5 h_6 v_7 h_8 v_9 h_{10} v_{11} h_{12} v_{13} h_{14} v_{15} \dots h_{16} v_{17} h_{18} v_{19} h_{20} v_{21} h_{22} v_{23} h_{24} v_{25} h_{26} v_{27} h_{28} v_{29} h_{30} v_{31}$$
- where **v** are vertical planes and **h** are horizontal planes of modules; number of planes is counted from 0 through 31
- Block assembly starts from plane-31 (**v₃₁**) on the assembly table and ends with plane-0 (**h₀**)
 - All planes in each block are glued together in a horizontal orientation on a block assembly table

NOvA Far Detector

- Far Detector (**FD**) consists of 28 blocks: **FD** → **B₀B₁B₂B₃B₄B₅.....B₂₃B₂₄B₂₅B₂₆B₂₇**
- where the number of blocks is counted 0 through 27
- Each block is 15.6 m wide by 15.6 m high by 2.141 m thick.
- The PVC in a 32-plane block weighs 177.7 metric tons
- The weight of a 32-plane block is 487.5 metric tons when filled with liquid scintillator
- Far Detector consists of 896 planes



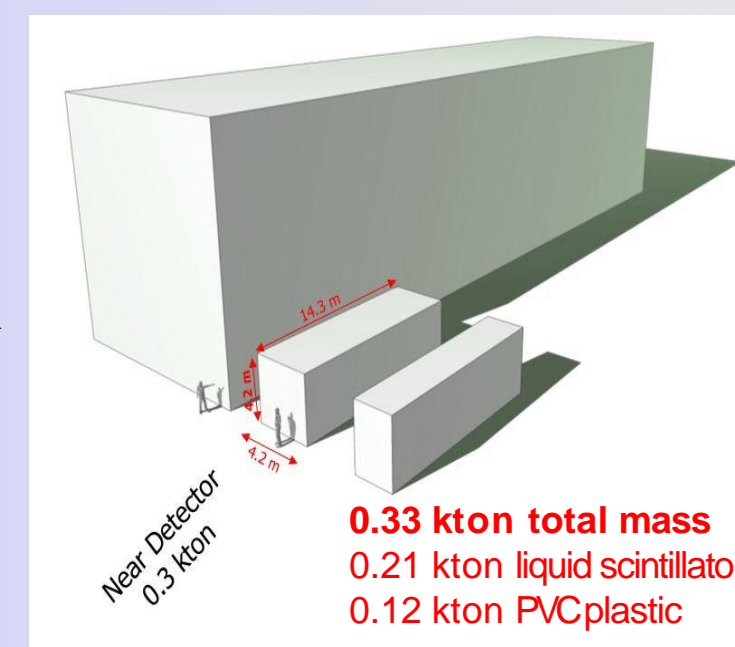
NOvA Near Detector

- The Near Detector (**ND**) consists of 8 blocks:

$$ND \rightarrow B_0 B_1 B_2 B_3 B_4 B_5 B_6 B_7$$

where the number of blocks is counted 0 through 7

- Each block is 4.2 m wide by 4.2 m high by 2.136 m thick
- The PVC in a 24-plane block weighs 5 metric tons
- The weight of a 24-plane block is 13.75 metric tons when filled with liquid scintillator
- The NOvA Near Detector consists of 192 planes



NOvA Near Detector Cavern

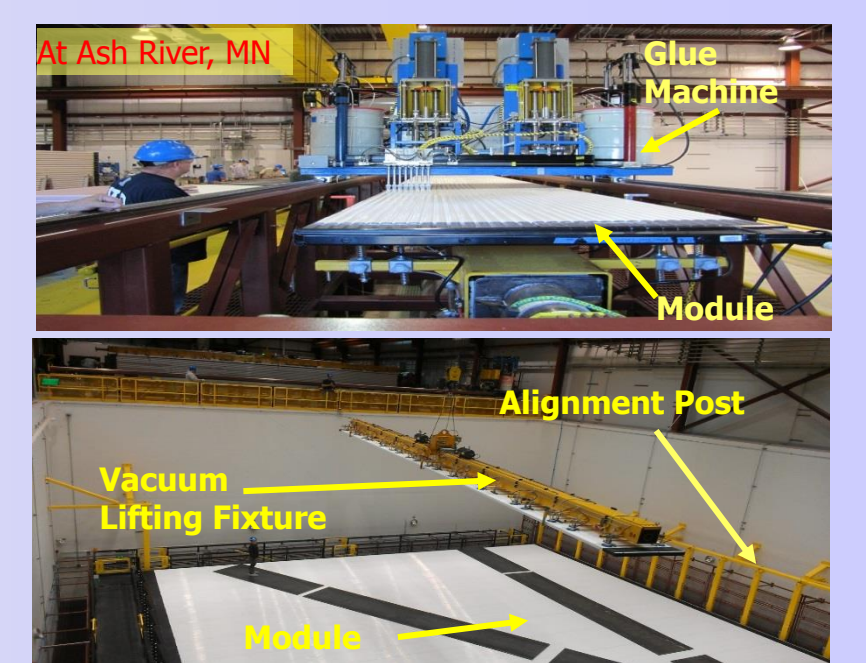
- Near Detector similar to the Far Detector
- Located on the Fermilab site about 1 km from the NuMI target
- Cavern is 105 m underground adjacent to the MINOS access tunnel, downstream of the MINOS shaft
- The cavern is 6.0 m wide by 20.5 m long by 6.0 m high

NOvA Far Detector Building

- 20.4 m wide by 113.8 m long with the detector section sunk 16 m below the existing grade into granite rock at the site
- Detector Hall at the south end
- Block Assembly area at the north end
- The Detector Hall will house all the 28 NOvA blocks

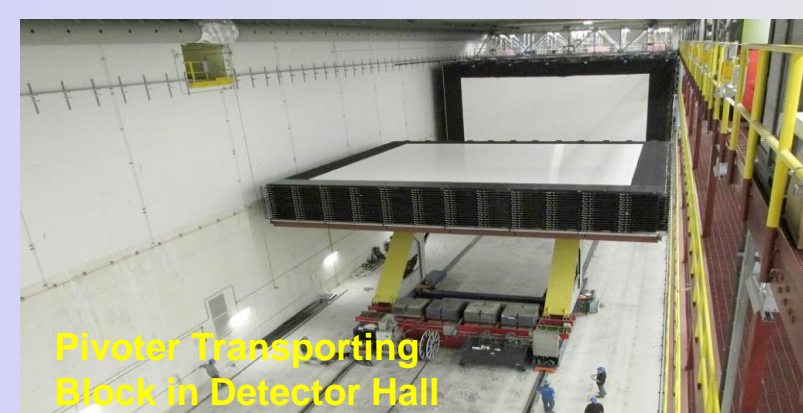
Far Detector Block Assembly

- Block assembly starts at the glue machine where glue is applied to the extrusion modules
- Modules are then transported to the assembly table by the vacuum lifting fixture to be glued to the next modules to form planes (layers)
- Block assembly starts in the horizontal position from plane-31 (**v₃₁**) on the assembly table and ends with plane-0 (**h₀**).



Far Detector Block Assembly

- Once a block has been finished, the Pivoter is used to move the block into place within the detector building to the south wall
- It then pivots 90° to set the block upright to the ideal location
- The block is then filled with Liquid Scintillator



Far Detector Plane Measurements

- The surface of each module plane of the NOvA Block is scanned with the HD56100 Scanner located on the ceiling inverted directly above the Pivoter Assembly Table
- Overall Block Survey Tolerance:
 - Relative 2 mm (Horizontal) edge to edge;
 - Relative 0.75 mm or better (Vertical) between adjacent module pieces
 - Angular tolerance of ± 2 mm/15.6 m = ± 0.13 mrad

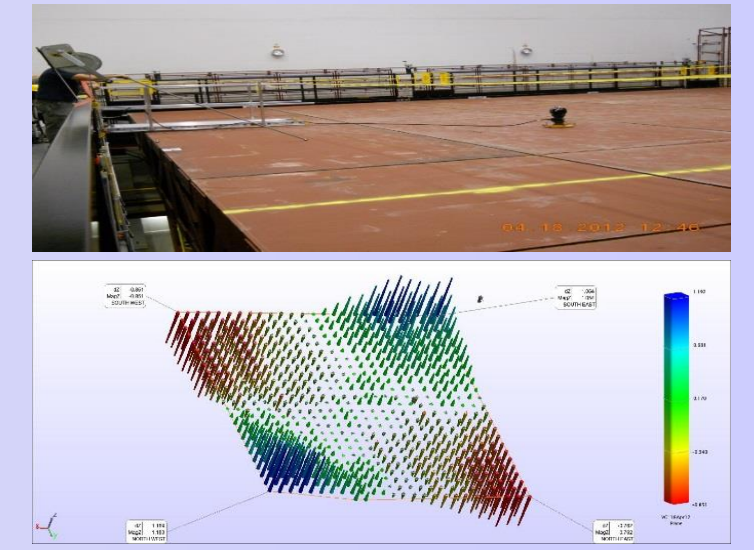
Near Detector Plane Measurements

- Groove measurements on Block will be made at specified locations by placing the SMR where the horizontal module grooves intersect the extreme end of the vertical plane
- The bottom of the SMR will sit in the horizontal groove while the one side of the SMR touches the vertical plane
- SMR will be placed on every third groove from the left (-13) and right (+13) edges of the module, and on the middle groove (0)



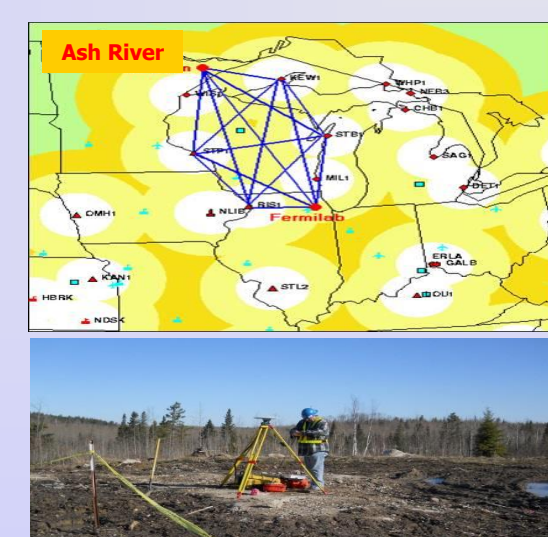
Far Detector Block Assembly Table Survey

- Block Assembly Table surface measured with the API Tracker using 61 cm x 61 cm grids
- Measurements made with the Table in the horizontal position using the API Laser Tracker
- Measurement results are used for shimming the Table surface before block installation
- Surface elevation differences range from -20 mm to 30 mm



Far Detector Surface Geodetic Network

- Established a GPS surface geodetic control network that connects points at Fermilab to Ash River
- Tie surface control network to the National Geodetic Survey's Continuously Operating Reference Stations (CORS) precision geodetic network
- All long baselines are known to better than 1 cm horizontally and vertically
- The network based on the NAD83 (North American Datum 1983) for horizontal datum and the NAVD88 (North American Vertical Datum 1988) for vertical datum

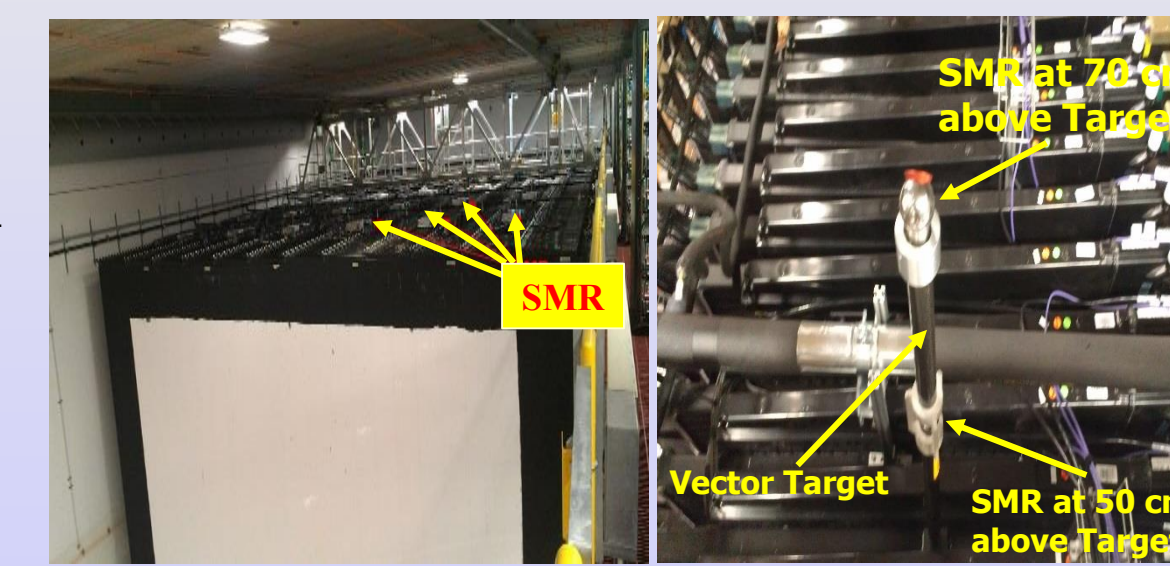


Detector Hall Control Network

- Established a precision control network in the Far Detector building for positioning the Far Detector using the API Laser Tracker
- Extended control network on the four levels of the west wall of the Detector hall using the AT401 Tracker
- Tied the new building control network to the surface network using the Geodimeter Total Station
- Precision control network in the Near Detector Cavern just completed using the API Tracker

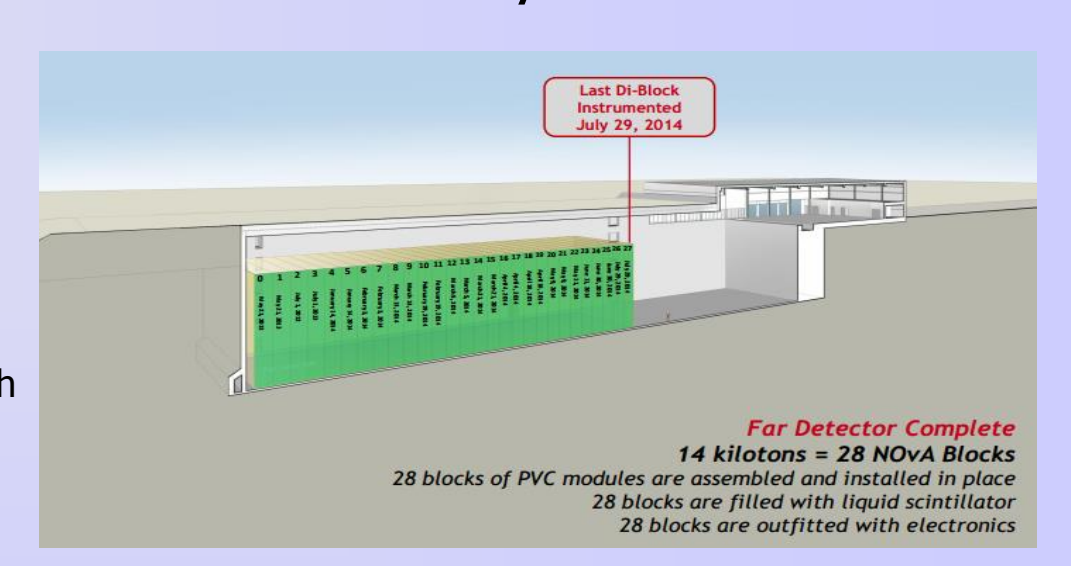
Far Detector Block Survey

- AT401Tracker on a wall bracket mounted up near the ceiling of the Far Detector hall
- Measurements made with AT401 Tracker using a vector target with SMR at both 50-cm and 75-cm above target on extension rods. The rods were attached to block targets glued on the block. The two measurements at each target were used for vector computation
- Each block has 8 targets - 4 on the Top, 2 on the West side and 2 on the East side



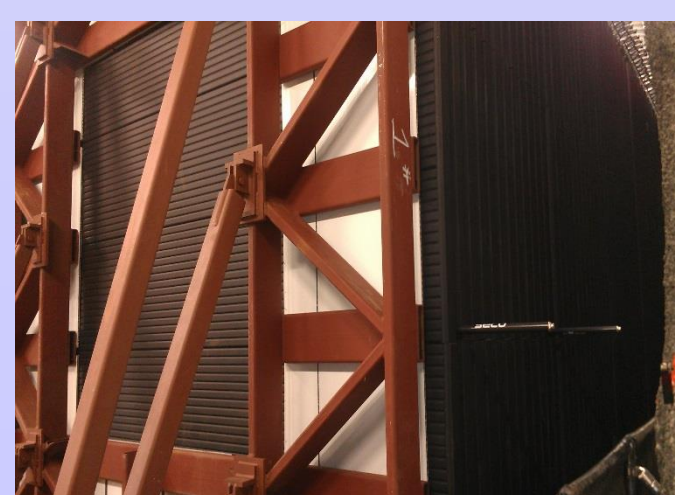
Far Detector Block Survey

- Block0 and Block1 surveyed with and without filled liquid scintillator
- Block2 through Block6 surveyed with filled liquid scintillator
- Block7 through Block12 surveyed without filled liquid scintillator
- Block13 through Block27 surveyed with filled liquid scintillator
- Survey was completed in March 2014



Near Detector Block Survey

- As-Built survey of the 8 Near Detector blocks was performed
- Measurements were made with API Radian Laser Tracker using SMR on 50-cm extension rods attached to block targets glued on the block
- Each block has 8 targets - 4 on the Top, 2 on the West side and 2 on the East side



Near Detector Block Survey

- Block0 through Block7 surveyed with and without filled liquid scintillator
- Survey was completed in March 2014



NOvA Neutrino Experiment Results

NOvA's new neutrino oscillation physics results are presented at Neutrino2016 in London on July 4, 2016.
<https://www-nova.fnal.gov/>

Acknowledgment

- We would like to thank
 - Alignment and Metrology Department members who participated in the NOvA Detector survey, especially Gary Crutcher and Chuck Wilson
 - Dr. Pat Lukens and Dr. Ting Miao of the NOvA Collaboration

