



# NOvA Project: Description and Status

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Project Manager



# Science overview

- NOvA is an acronym
  - **N**uMI **O**ff-axis  $\nu_e$  **A**ppearance
    - (and NuMI is another acronym: Neutrinos at the Main Injector)
- NOvA is designed to look for  $\nu_\mu \rightarrow \nu_e$  oscillations
  - One of several experiments to measure  $\sin^2(2\theta_{13})$ 
    - Just a theory parameter related to the probability of electron neutrino appearance
      - At the current experimental limit, in a 6 data year run, NOvA would see 150 electron neutrino events on a background of 22 fake events
      - At the limit of NOvA's detection ability, we would see 15 events on the same background of 22
  - First look by any experiment at the mass hierarchy
    - Which neutrino species is heavier
  - First look by any experiment for CP violation in the neutrino sector
    - Related to matter / anti-matter asymmetry in the universe?



# Project overview, the quick version

- **Project components:**

- Accelerator and NuMI Upgrades

- 700 kW beam vs. current 320 kW for MINOS
  - This work requires an 11 month shutdown in 2012
- Recycler converted from anti-proton storage ring to a proton storage ring/  
pre-injector into the Main Injector once the Tevatron Collider program ends
  - New kickers to get beam in and out of Recycler & Main Injector
- Main Injector cycle time reduced from 2.2 sec to 1.5 sec with Recycler
  - Reduce further to 1.33 seconds with 2 more RF stations
- Upgrades to NuMI beamline to handle 700 kW

- Detectors

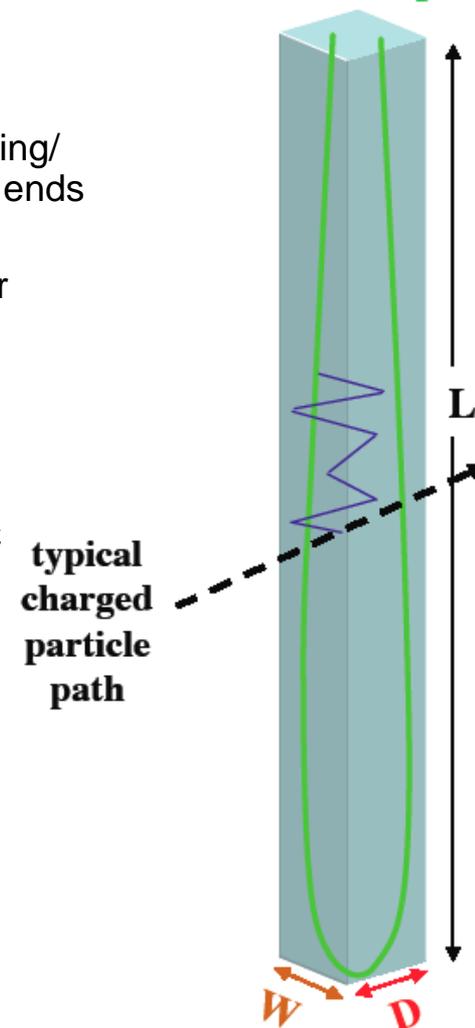
- 14,000 ton Far Detector & a 220 ton Near Detector
- Liquid scintillator, waveshifting fiber, Avalanche Photo Diode @  $-15^{\circ}\text{C}$
- Far Detector has 357,120 cells:
  - each 15.5 m long, 4 cm wide, 6 cm deep
- Detectors are “off-axis” to the NuMI beamline by 14.6 mrad  
which gives a ~ mono-energetic beam at 2 GeV

- Buildings

- Far Detector is at Ash River, Minnesota (near International Falls)
  - At 810 km from Fermilab
  - So L/E is ~ at the minimum of surviving muon neutrinos
- Cavern underground at Fermilab for Near Detector

- **Total Project Cost is 278 M\$ -- 90 M\$ obligated to date**

To 1 APD pixel

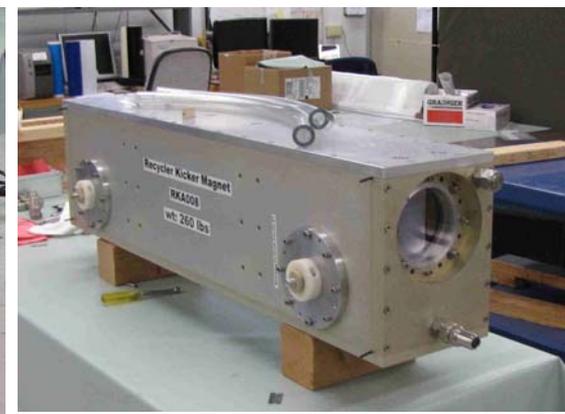
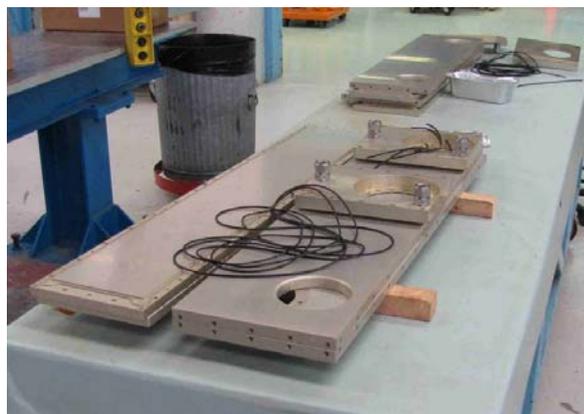
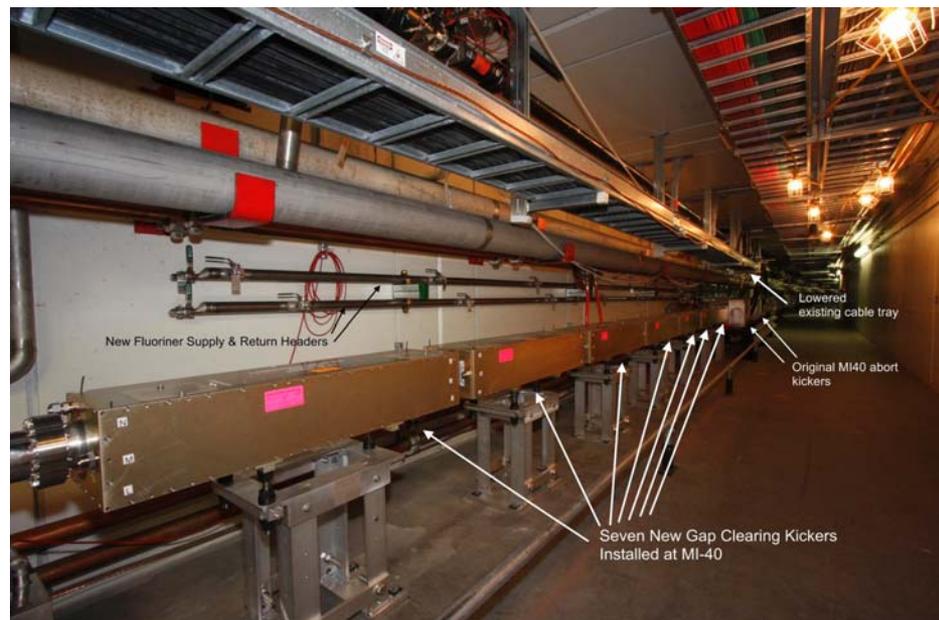




# Accelerator and NuMI Upgrade progress

- Kicker design and procurement
  - First Kicker installed
    - in Main Injector for gap-clearing with MINOS
    - This work is off-project on Accelerator Improvement Project (AIP) funds
    - 7 magnets (= 1 kicker) installed in the 2009 summer shutdown
    - This kicker moves up to the Recycler (just above in the picture) for NOvA
    - **This kicker has the most severe constraints on rise time and fall time and flattop stability, so much risk is now removed from NOvA**

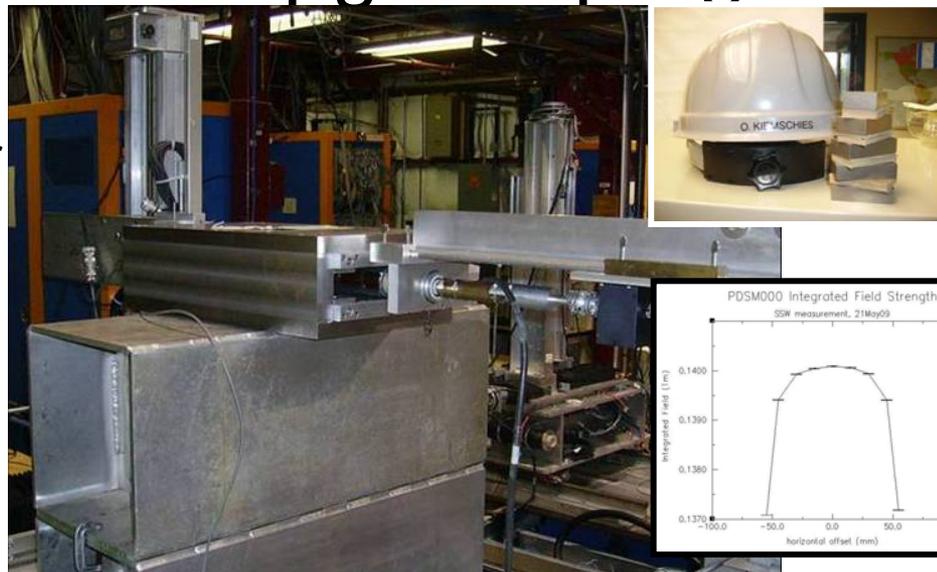
- Additional NOvA kickers are under construction





# Accelerator and NuMI Upgrade progress

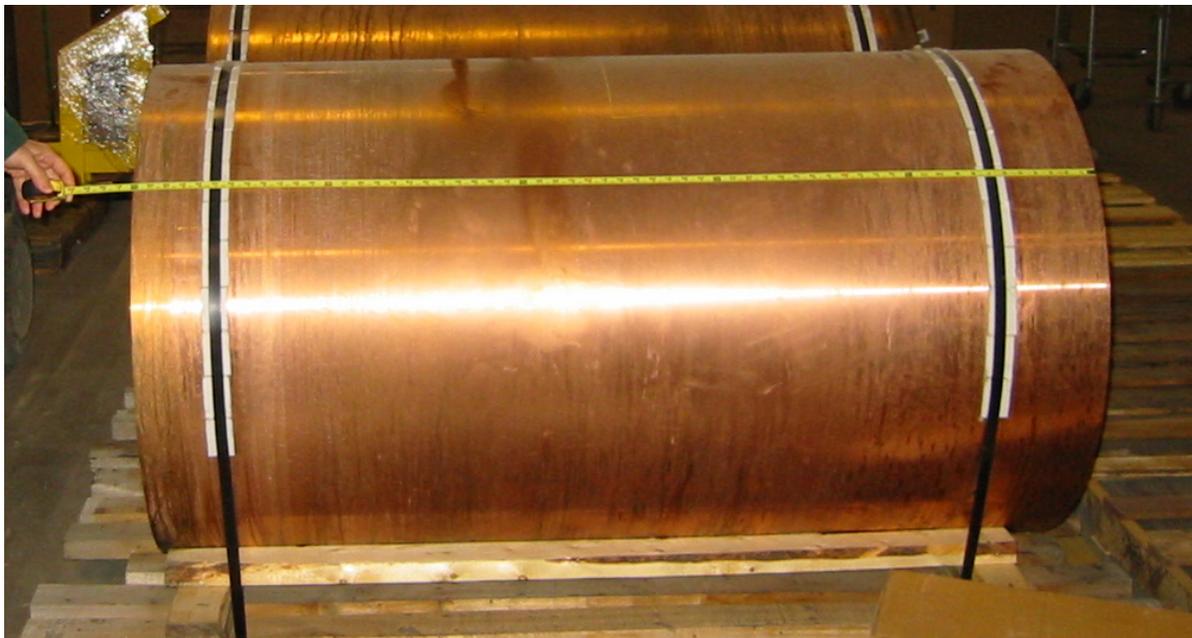
- Magnet design, testing, and manufacturing for Recycler and transfer lines
  - PDS (Permanent Dipole Short)
    - New magnet design using SmCo5
    - Prototype made externally, measured and meets expectations
    - Internal Design Review completed
  - PDD (Permanent Double Dipole)
    - Injection line requires 5 new magnets
    - Existing design, tooling, procedures and measurement not used for 10 years
      - Being resurrected in Tech Division
  - ADC\_W (Wide gap ADC)
    - Switch magnet from MI-8 line to Recycler injection transfer line:
      - preserving capability of Booster Neutrino Beam
    - Transfer line from Recycler to Main Injector
    - Modifying existing 8 GeV magnet to larger aperture:
      - Under test at 15 Hz,
      - Clarify beam pipe requirements
        - » Active cooling (eddy currents)





# Accelerator and NuMI Upgrade progress

- Beam Position Monitor cable delivery complete in December 2009
  - 330,000 feet  $\frac{1}{4}$  in heliax
  - Stored in PC4
- OFHC (Oxygen free high conductivity copper) shells for Recycler RF
  - Forged from copper ingots, ~6 months advance on schedule
  - 1.5 m long, 70 cm diameter, 2.5 cm thick

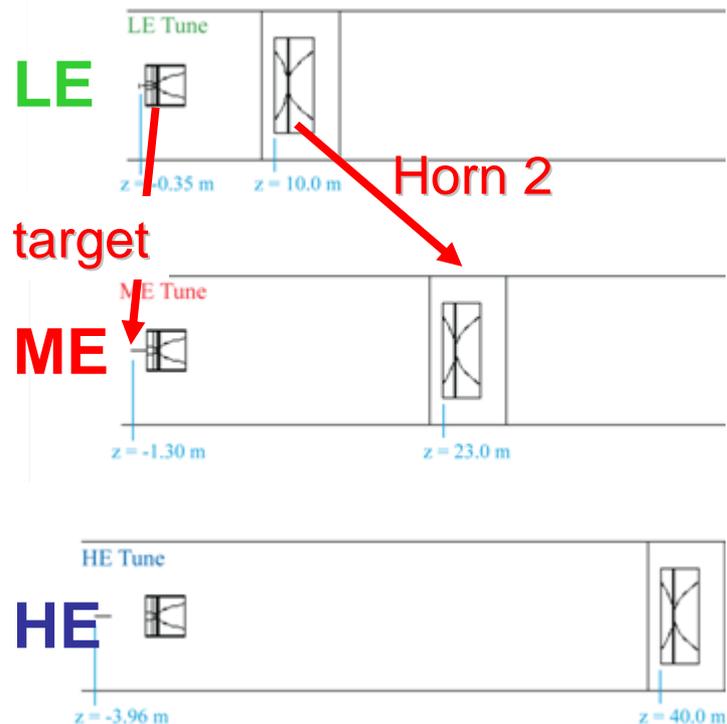




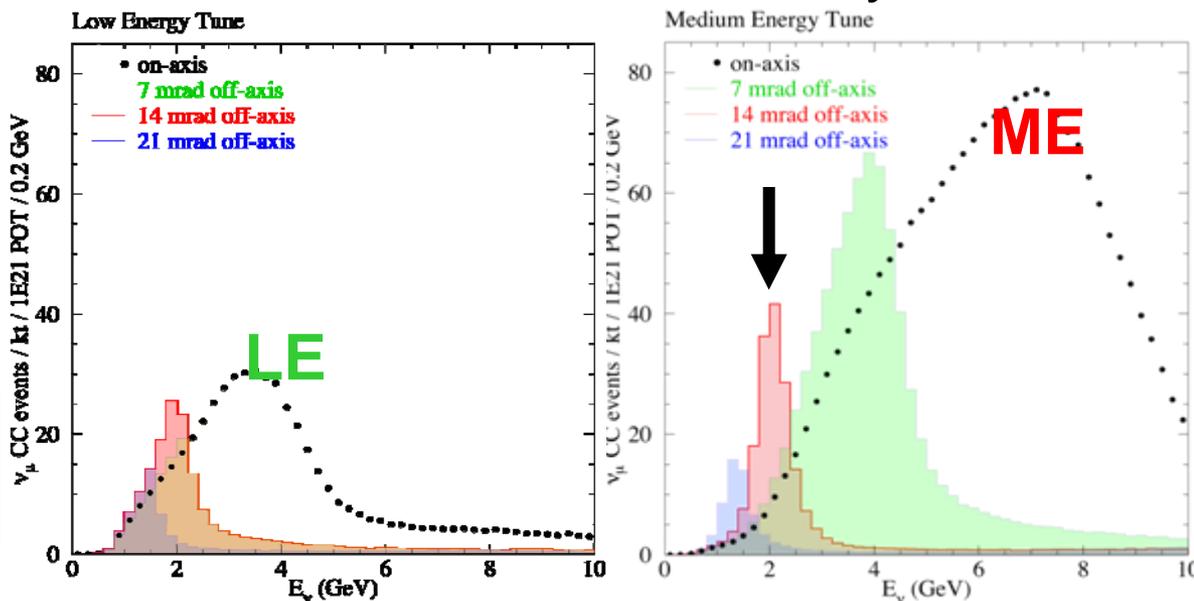
# Accelerator and NuMI Upgrades

## • NuMI Beamline

- New Medium Energy target, upstream from current low energy target
- Horn stripline extension so Horn #2 can move to medium energy position
- Cooling modifications and power supply upgrades to handle the 700 kW and faster cycle time



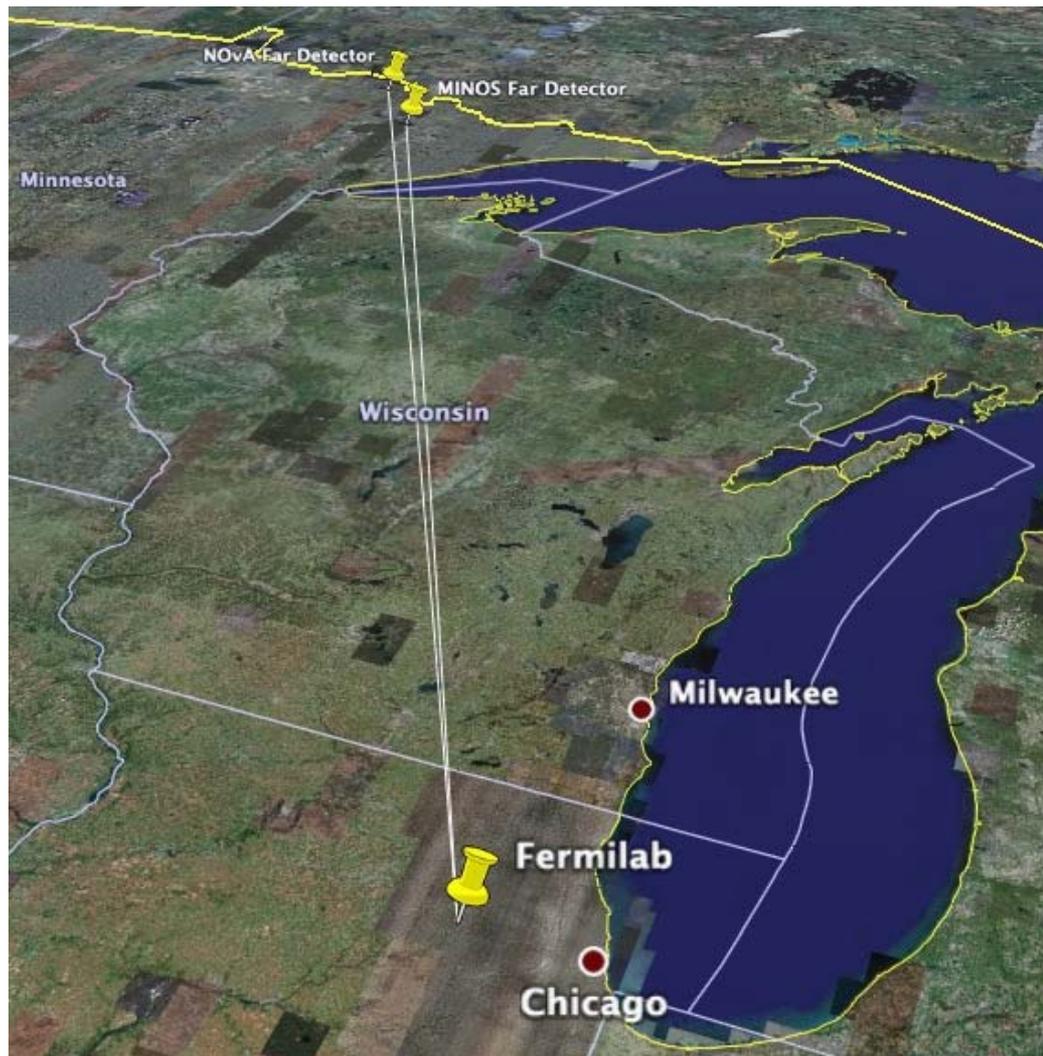
NOvA is off-axis at 14 mrad for increased 2 GeV  $\nu$  yield





# Ash River, Minnesota Site

- Farthest site from Fermilab within the US along the existing NuMI Beam that is accessible by all weather road
  - Does require a 3.5 mile long new road from the existing county road to the site
  - 810.5 km from Fermilab, just 1.5 miles south of Voyageurs National Park
  - West of the NuMI beam by 11.8 km (“off-axis”)
    - 2 GeV neutrino beam
  - **Site and access easements were purchased by the University of Minnesota**





# Access Road Progress on Far Detector site



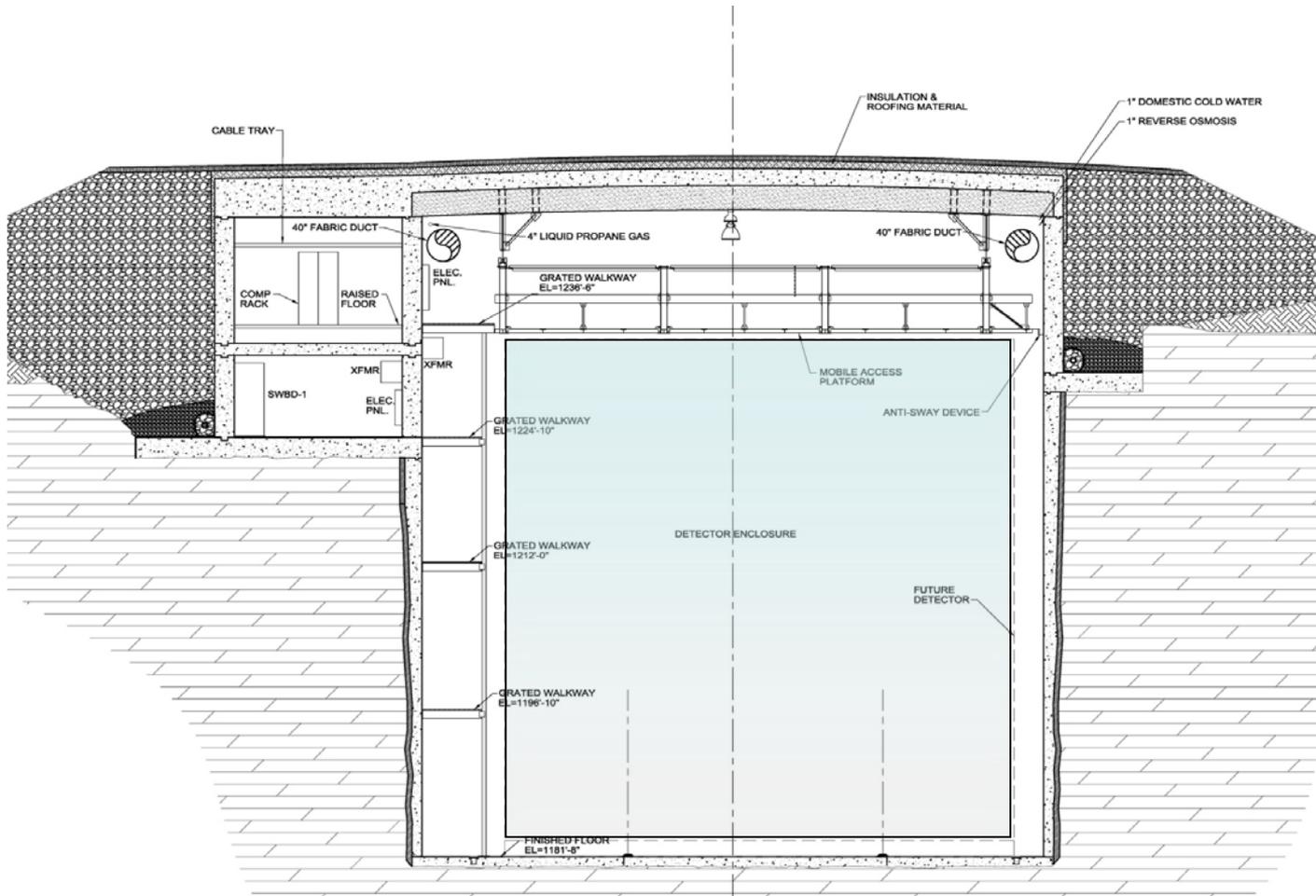
- The gravel phase of the 5.6 kilometer access road to the site is complete
  - 54,000 tons of granite Class 5 Aggregate base crushed on site and applied to the road.
  - Utility duct banks installed.
  - Paving next summer.





# Building is set in granite rock

- Cosmic Ray shielding
- Ease in secondary containment of liquid





# Far Detector Building progress at Ash River, Minn

- Views from the North looking towards Fermilab
- The excavation is down 20 ft over the entire building
  - Final lift will drop the pit another 24 ft.
    - That work began in February
  - Part of the Service Building at the north end of the pit is done.



June 2009



Aug 2009



Dec 6, 2009



Nov 2009



Feb 1, 2010



# Far Detector Building progress at Ash River, Minn

- View from the West
  - **Building is full ~ 400 ft length, ~75 ft wide, 20 ft deep**
  - Exposed walls have been rock-bolted



Aug 2009



Dec 6, 2009



Rock bolts installed in all walls of first lift



Nov 2009



Feb 1, 2010



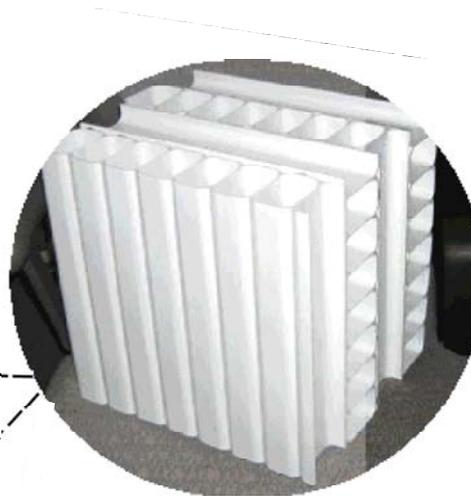
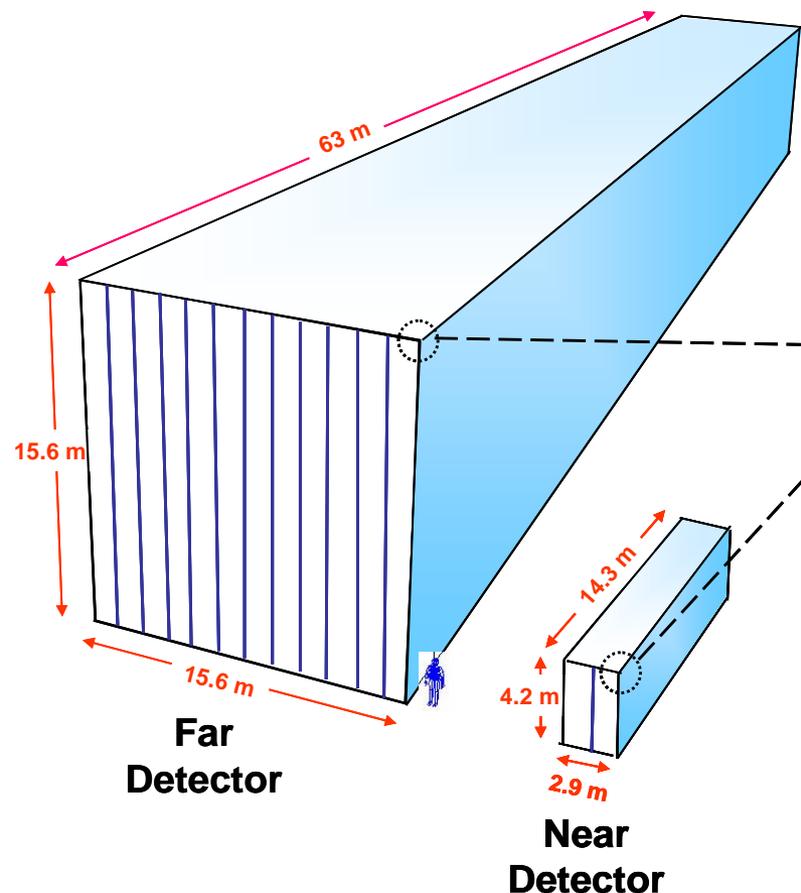
# Feb 4 blast to lowest level, down 44 ft

Using “smooth wall” blasting technique vs. earlier “pre-split” technique





# NOvA assembles TWO Detectors



Both have successive layers of vertical and horizontal PVC cells bonded together with adhesive

- 14,000 ton **Far Detector**
  - 12 by 12 extrusion modules, 930 layers
- 222 ton **Near Detector**
  - 2 by 3 extrusion modules, 206 layers
  - 300 feet underground at Fermilab
  - Operates first on the surface at Fermilab



# Detector progress

- **Scintillator**

(3 million gallons)

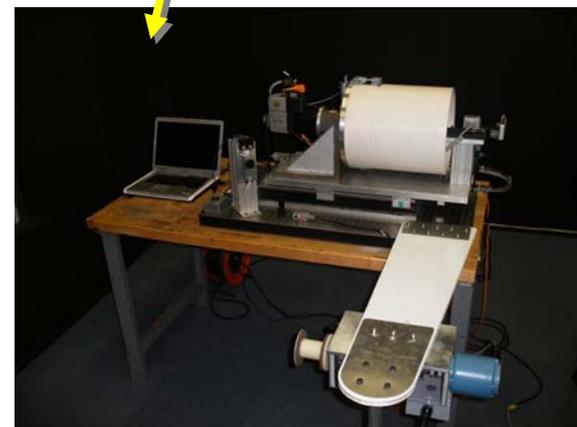
- We have blended 4,500 gallons at Fermilab
- P.O. out and deliveries continue for waveshifters - PPO and bis-MSB
- Have changed to brighter scintillator than in TDR
  - 25% more fluors = 12% more light
  - Reduce risk of weak detector signals
- Have blended 4,500 gallons at Fermilab
- **Next step: Toll blending of scintillator for Near/Far Detectors**
  - Select >1 vendor to blend 30,000 gallons each (competition)
  - Winner blends the full 3 million gallons
  - And stores a buffer of incoming mineral oil and outgoing scintillator



- **Waveshifting Fiber**

(11 million meters)

- P.O. in place for all the fiber
- Have 100 km of fiber in hand
  - QA complete at Michigan State
- **1st 350 km of production fiber delivered Feb 5**



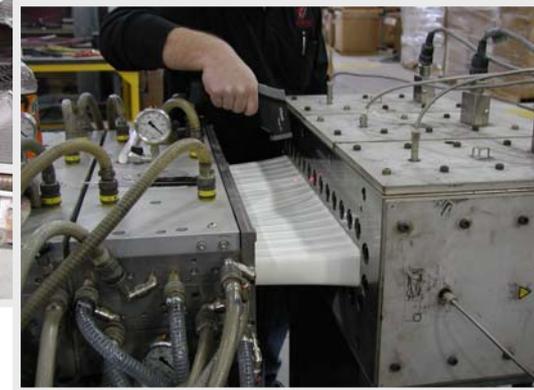
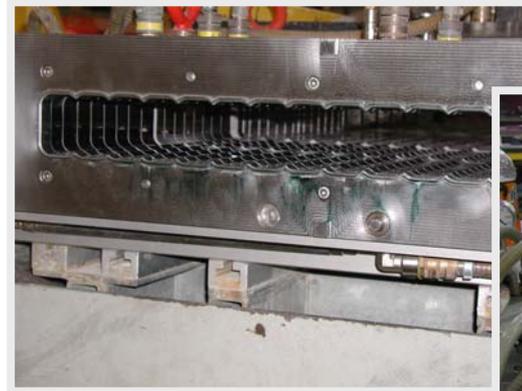


# Detector progress

- **PVC Extrusions** (25,000 fifty foot objects)
- Extrusion dies on order
  - Dies expected this week
- P.O. in place to make all 16-cell extrusions for the far detector
  - 9.4 M\$
  - Vendor: Extrutech Plastics
    - ordered a new twin screw extruder capable of 1100 pounds per hour
    - Ordered on 12/16/09 (their money) once they got the Fermilab P.O. -- delivered and installed last week
- QA plan in place
  - reviewed by Fermilab and ANL engineers on
  - Recommended additional automation
    - Reflectivity, Impact test,
    - Vacuum test (on alternate cells)
    - Dimensional & Flatness testing with purchased camera system
- Team working on RFP for 11 million pounds of PVC resin
  - Preproduction deliveries in April



Prototype die





# Detector Module progress



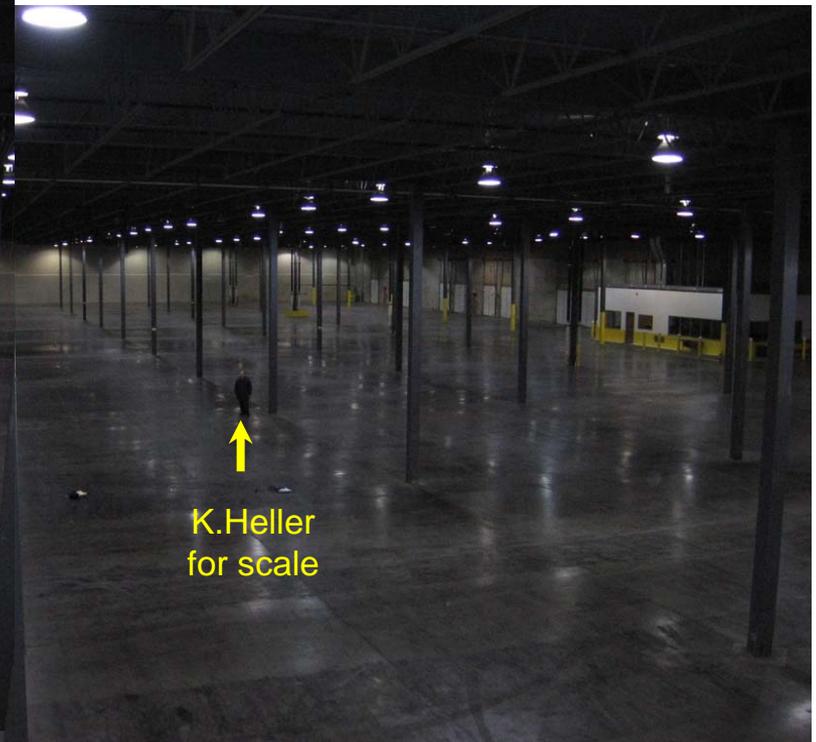
Jan 27

- University of Minnesota factory
  - Lifting fixtures
  - Tables to glue two 16 cell extrusions together to form a 32 cell “module”
    - Robot to check for step at glue joint
  - Bubbler to test for leaks on multiple modules at once
  - Fiber stringer, fiber tester
  - Glue machines
- Internal engineering review of University of Minnesota factory complete
  - Some additional safety engineering required, e.g. on the lifting fixture
- **Began construction of Near Detector modules on Jan 20**
  - Picture shows 1<sup>st</sup> 7 Near Modules prepped for pressure tests
  - 25 modules now complete
  - Rate is 3/day, need 7/day



# Far Detector Module Factory progress

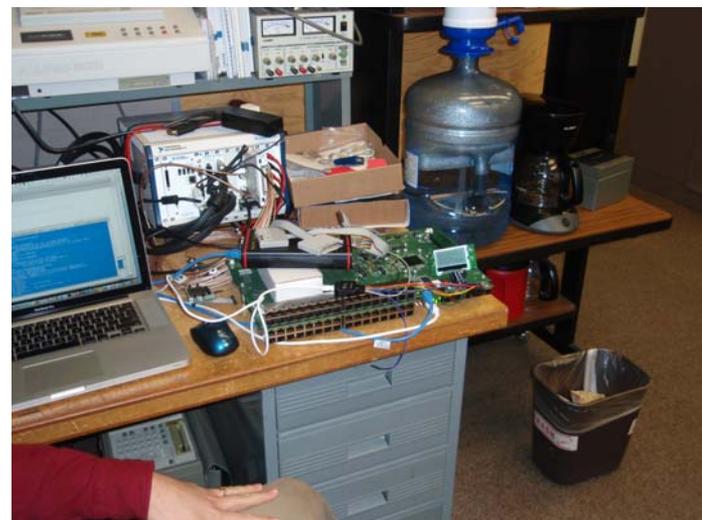
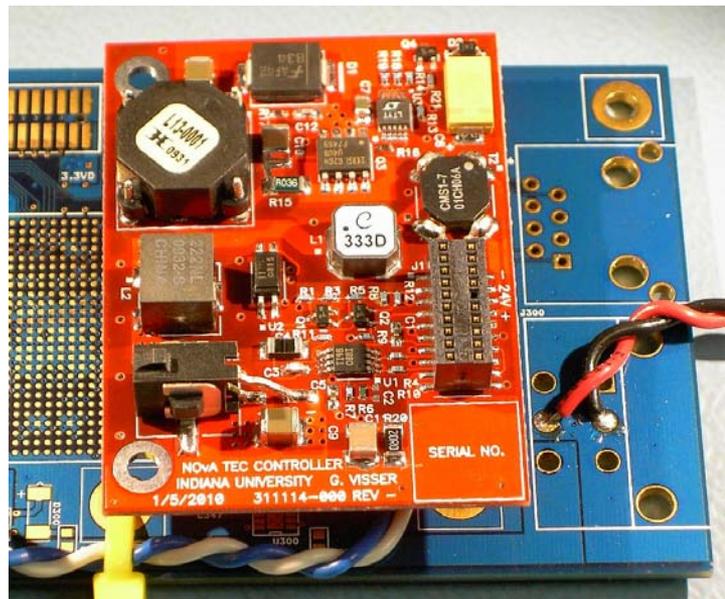
- NEW Warehouse rental space at the University of Minnesota for factory
  - 125,000 sq. ft
    - Use  $\frac{1}{2}$  for factory,
    - Other  $\frac{1}{2}$  for storage of incoming extrusions or outgoing assembled modules
      - This gives us buffer space
  - Regents approved in Dec 12, 2009 meeting
  - Fermilab P.O. to U.Minn. for space rental issued Jan 26
  - Owner outfitting of space for NOvA to begin soon after lease signed (goal is this week)





# Electronics & DAQ Progress

- Avalanche Photo Diodes (APDs)
  - First 20 APDs with final tweaked design **arrive in March**
  - All 550 Near Detector APDs in hand **mid July**
- Front End Board (FEB) v4 design done 
  - Thermo-electric Cooler control board also done
  - One FEB needed per PVC module, so 32 channels per board
  - 70 Near Detector FEBs early available early May, balance of 550 in **early June**
- Data Concentrator Modules(DCM) 
  - Each DCM reads out 64 FEBs
  - 1st production DCM boards available, 4 of them now booting up
  - Expect DCMs for the Near Detector in **early May**
- Time Distribution Units (TDU), GPS tag
  - 2 boards stuffed and checked, firmware development underway
  - expect TDUs for the Near Detector in **mid April**

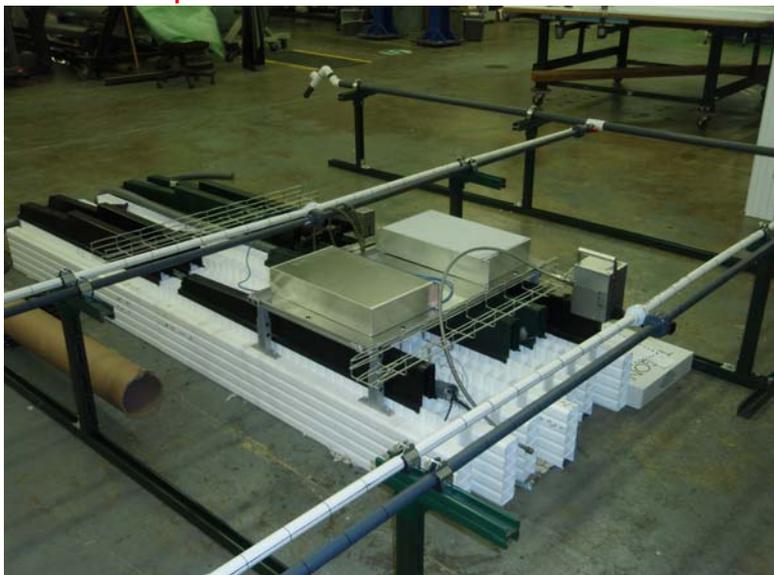




# Electronics & DAQ Progress

- Power Distribution
  - Final version of Power Distribution Board in circuit board design/fabrication
  - Low voltage power supply chosen (Wiener PL506)
  - High voltage power supply still in evaluation (Wiener, CAEN)
  - Mocking up the detector for PS, cable trays, cables, water cooling:

Top of detector



Side of detector





# Vertical Slice 5 Prototype progress

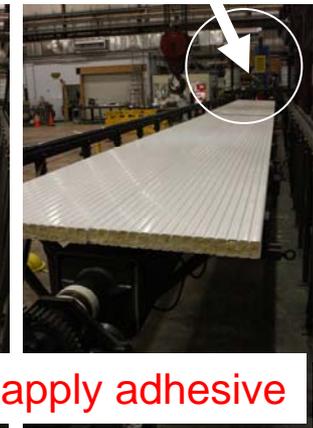
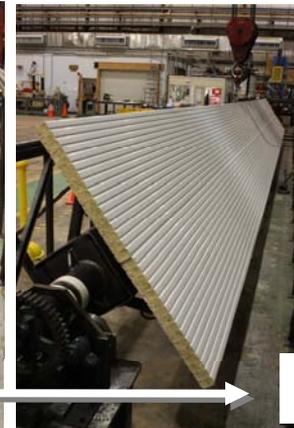
- Two full size modules at CalTech for tests
  - “Production” modules from Minnesota delivered on **December 13**
  - Scintillator delivery scheduled in **February**
  - Electronics available in **March**
- **Cosmic ray test of 32 cells in a full length module.**
  - Vertical Slices 1 – 4 tested short PVC with full length fibers and different scintillator mixes
  - VS-5 is the last such prototype





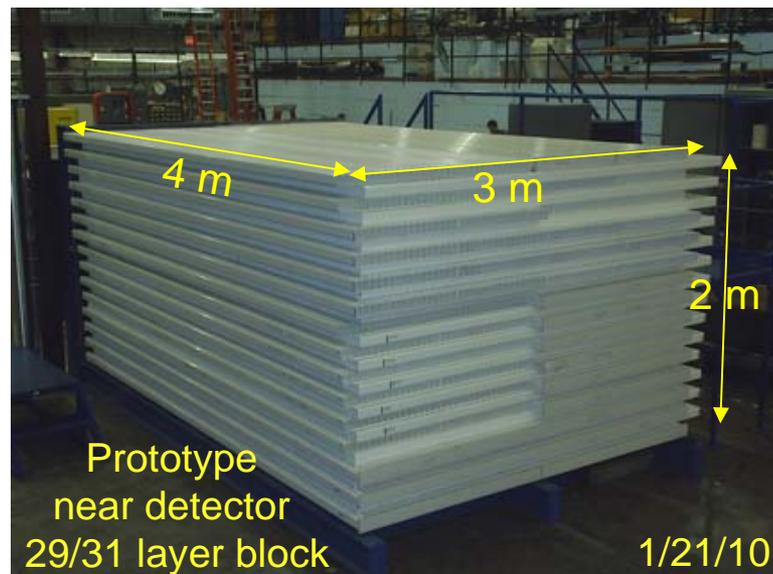
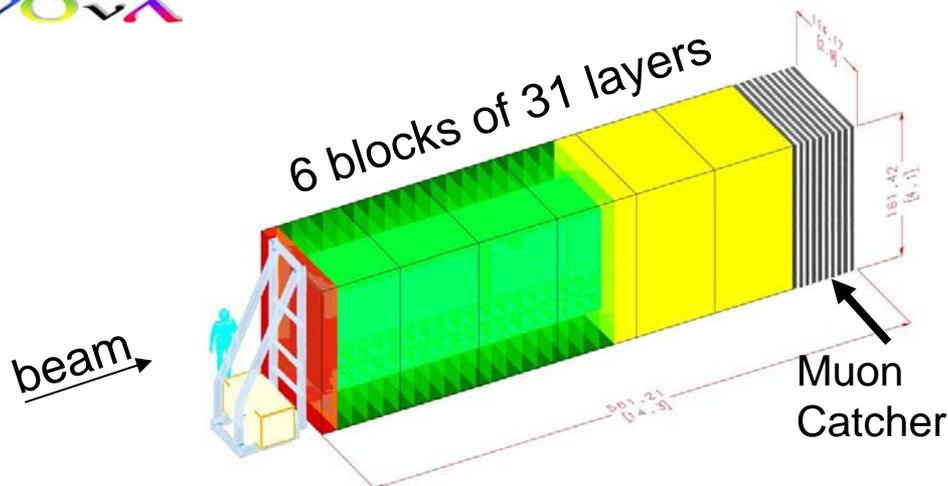
# Vacuum Lifting fixture & Glue Machine

- The Vacuum Lifting fixture picks up a full 50 foot 10 inch long PVC module
- In the Adhesive Machine, the PVC module is rotated so the bottom side is up.
  - Next the Adhesive Machine applies a two-component adhesive to the PVC from 55 gallon drums shown in the upper right picture. The Adhesive carriage moves along rails up and down the length of the PVC module.
  - Finally the PVC module is turned right-side-up and removed from the machine to be placed on the block under construction.

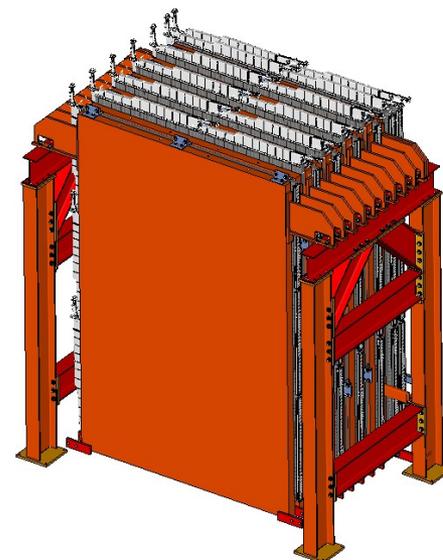




# Near Detector Assembly progress



- **This is a big device on its own**
  - 220 tons, about 14 meters long
  - Similar in size to NuTeV but (not as dense)
- Prototype near detector block
  - 29/31 layers dry stacked (Jan 21 at ANL)
  - Learn stacking/alignment techniques
  - **Glued assembly started last week**
- Real Near detector block assembly begins in mid March
- Muon Catcher Design complete
  - 10 layers of 4" steel with a layer of PVC modules after each layer





# Near Detector Building progress

- New building near MINOS service building
  - Precast concrete construction – VERY fast
  - Construction started - Dec 7
  - Walls up in 2 working days – Jan 26/27
  - Roof, windows, roll-up door last week
  - Pour concrete floor week tomorrow

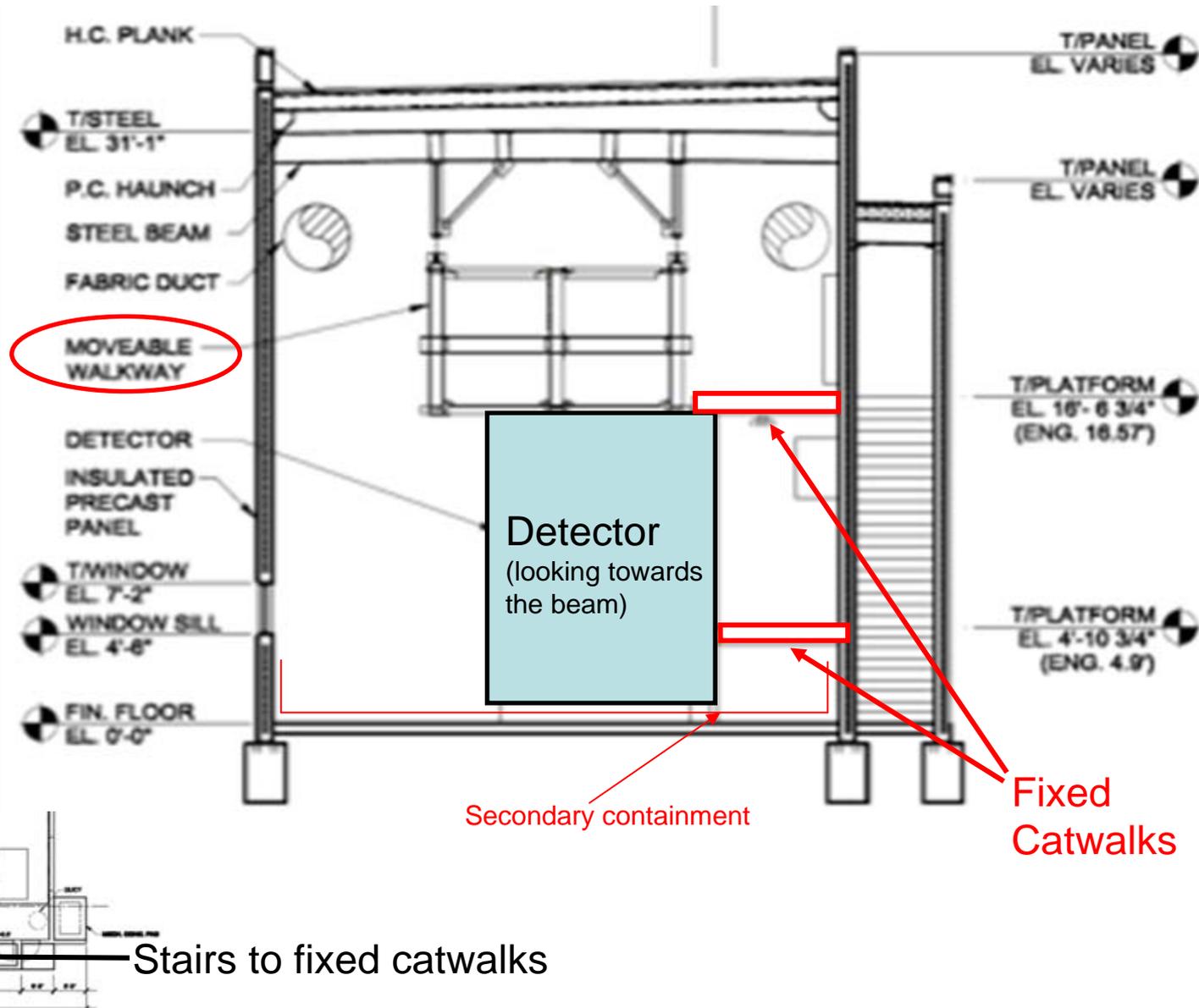




# Near Detector Building progress

- **Full mock up of catwalks and movable platform above the detector**

- Learn about assembly issues at Ash River
- Reduce risk for Ash River assembly

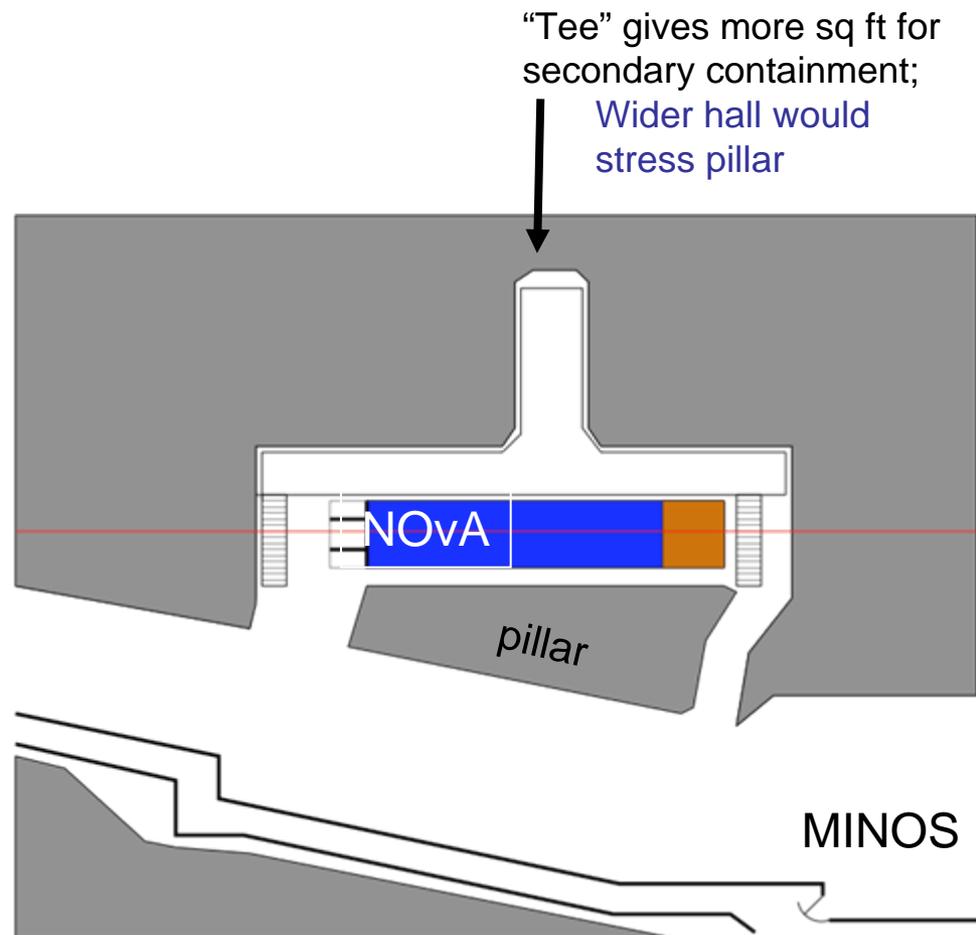


Plan View



# Near Detector Cavern progress

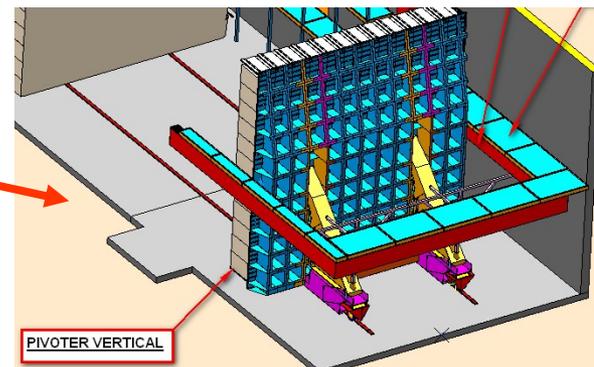
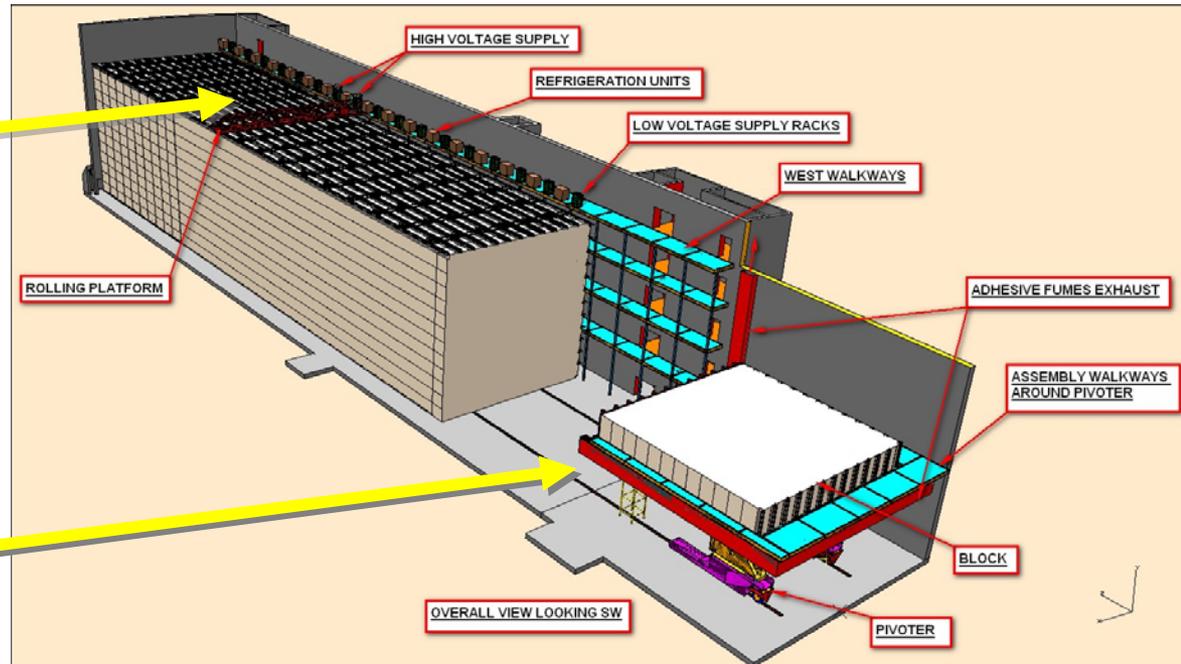
- New NUMI Cavern 300 ft underground
  - Kick Off meeting with Montgomery, Watson, Harza; Cavern A&E Firm, Dec 4, 2009
  - “As built” of NuMI areas complete
  - Life Safety Report came in Feb 10
  - Project Definition Report due March 19
  - Design 50% complete due Sept 1
  - Completed Design due Dec 10
- The cavern gets constructed during the 2012 shutdown for Recycler work





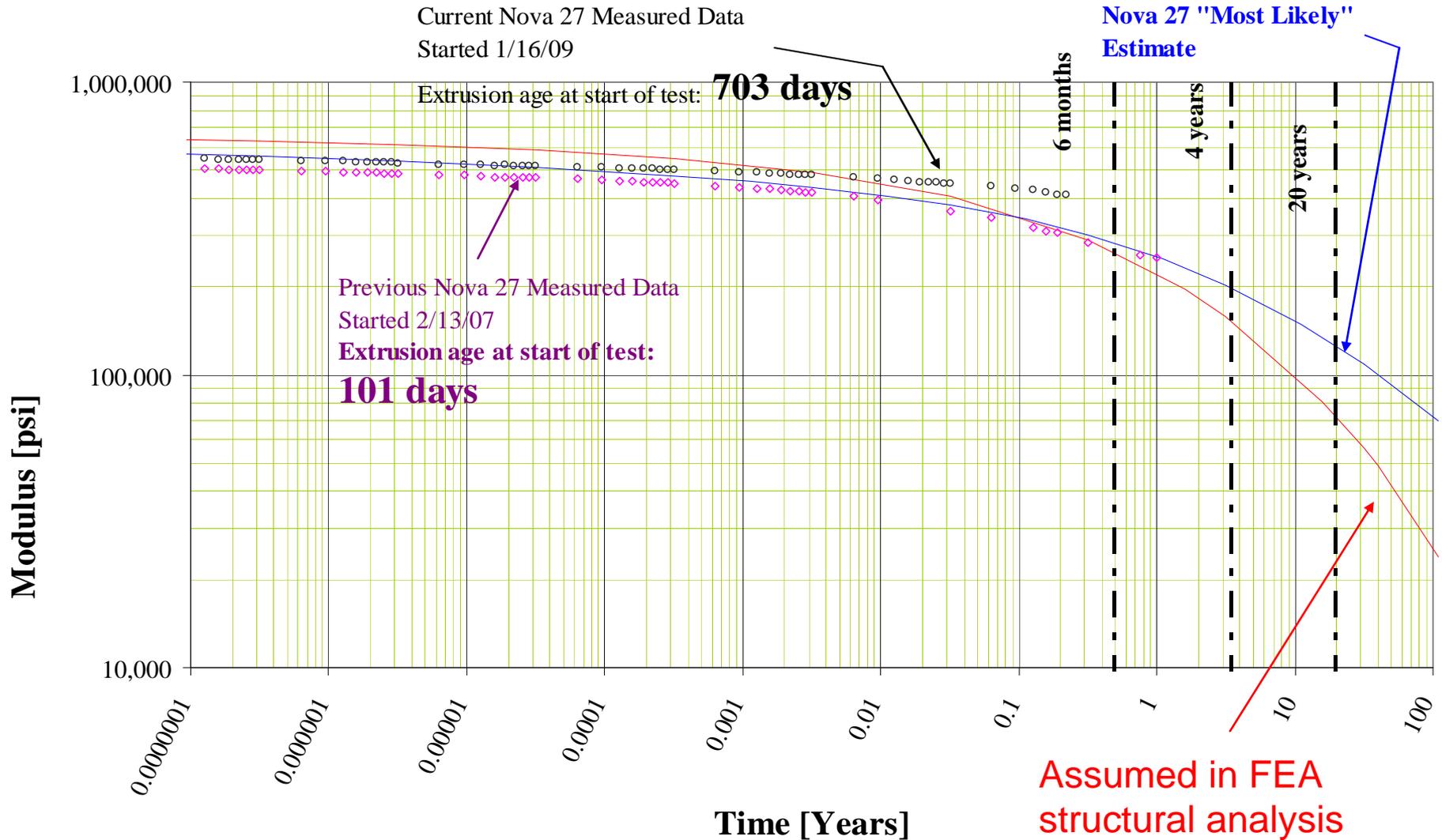
# Far Detector Assembly

- **Unique Structure**
- 5 stories high
- 220 feet long, 930 layers
- **MADE of PLASTIC**
- Filled with liquid
- Assembly in 30 Blocks
  - 1 block has 31 planes
  - Each plane has 12 extrusion modules built on a flat table
  - Extensive FEA and review of design
- **Block Pivoter**
  - Lifts 143 ton (empty) blocks from flat assembly position to vertical detector position





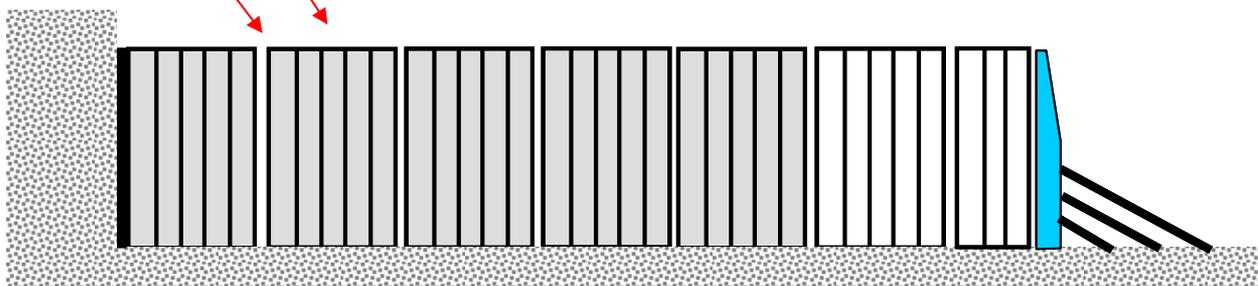
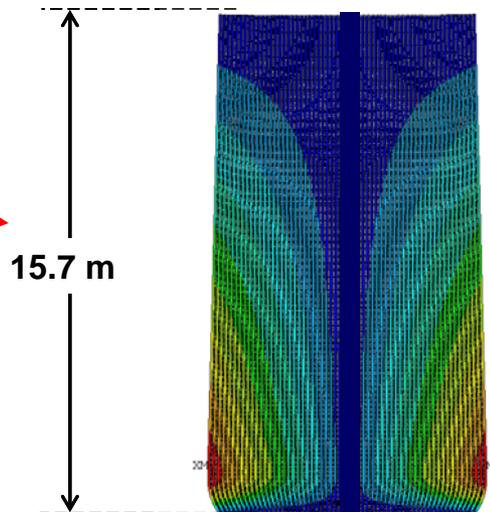
# PVC as a structural material: Creeps under stress





# Far Detector Assembly

- Build Thirty 31 plane blocks on a flat table
- **When vertical and filled with liquid scintillator, the blocks swell at the bottom and the PVC creeps**
- Superblock consists of 5 blocks “touching”  $< 2-3 \text{ mm}$  = not observable
- Leave expansion gap of 20 mm between Superblocks
  - When filled with scintillator, a superblock swells by 20 mm near the bottom of the blocks
- Fill during construction to speed assembly time
  - Filling follows by about a superblock
- Initial bookend is south granite wall
- Finally install strong bookend at end to resist further PVC deformation

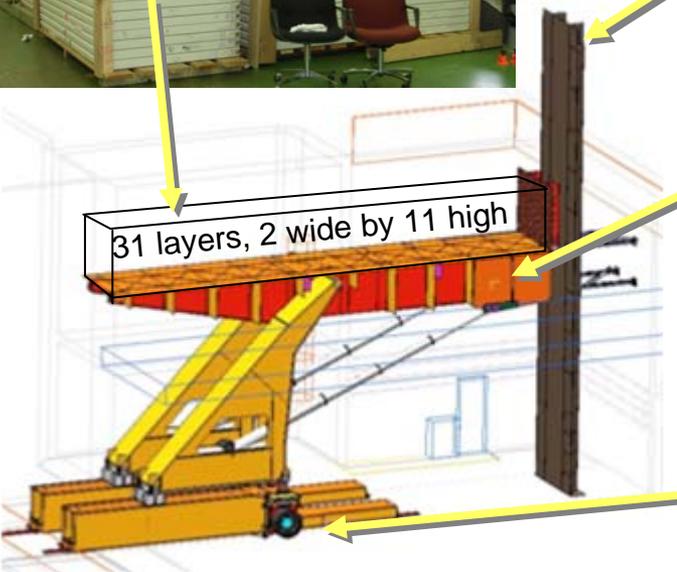
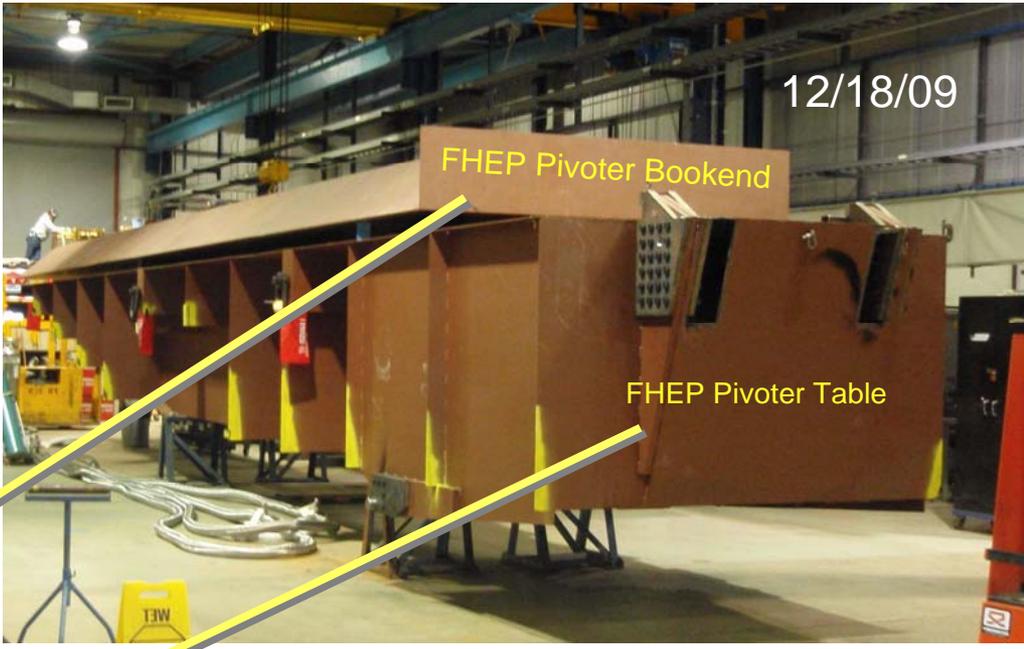


All superblocks up, 5 full

# Far Detector Assembly progress



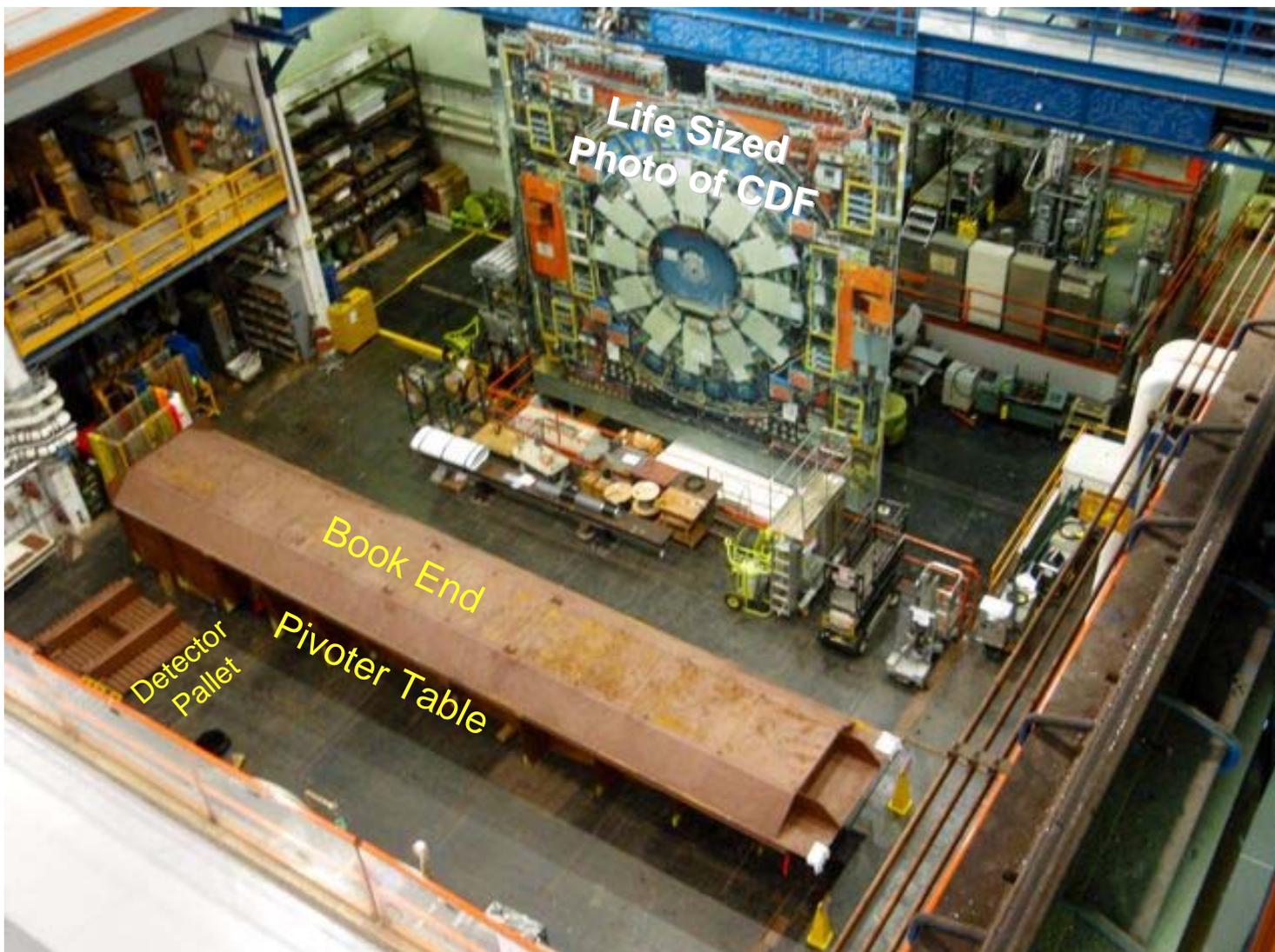
- Full Height Engineering Prototype (FHEP)
  - 1/6<sup>th</sup> of final pivoter needed at Ash River
  - Pivoter Table and bookend in hand
  - Drive system & wheels in hand
  - Test pivoter in early April at CDF
  - All FHEP modules in hand
  - FHEP PVC assembly begins in June



pivoter racing slicks



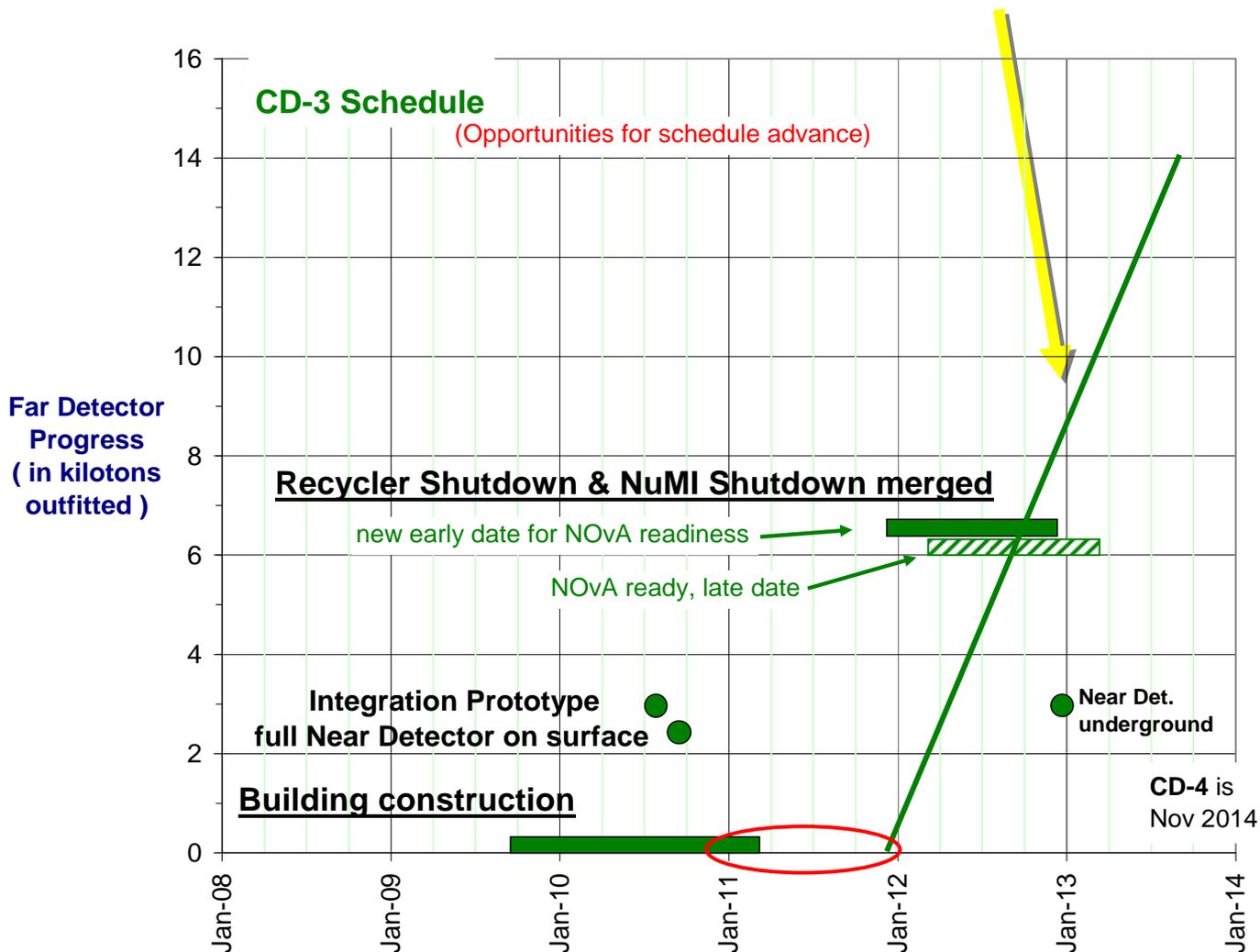
# FHEP Pivoter in CDF Assembly Pit





# Schedule

- NOvA comes out of the 2012 shutdown with > half of the Far Detector taking data & the full Near Detector in place and taking data.





# Reminder of just how big the Far Detector and Building are:

## NOvA 14 kt & deep pit of building in a football stadium

(wire frame of loading dock in black hangs out over the stands by 30 yards)

