NOvA technology

Jarek Nowak
University of Minnesota

NOνA: NuMI Off-Axis ν_e Appearance Experiment

Near detector protoblock

180 Scientists and Engineers from 26 Institutions

Argonne National Laboratory - University of Athens - California Institute of Technology - University of California, Los Angeles - Fermi National Accelerator Laboratory - Harvard University - Indiana University - Lebedev Physical Institute - Michigan State University - University of Minnesota, Duluth - University of Minnesota, Minneapolis - The Institute for Nuclear Research, Moscow - Technische Universität München, Munich - State University of New York, Stony Brook - Northwestern University - University of South Carolina, Columbia - Southern Methodist University - Stanford University - University of Tennessee - Texas A&M University - University of Texas, Austin - University of Texas, Dallas - Tufts University - University of Virginia, Charlottesville - The College of William and Mary - Wichita State University

NOvA – Totally Active Scintillator Detector

Project elements

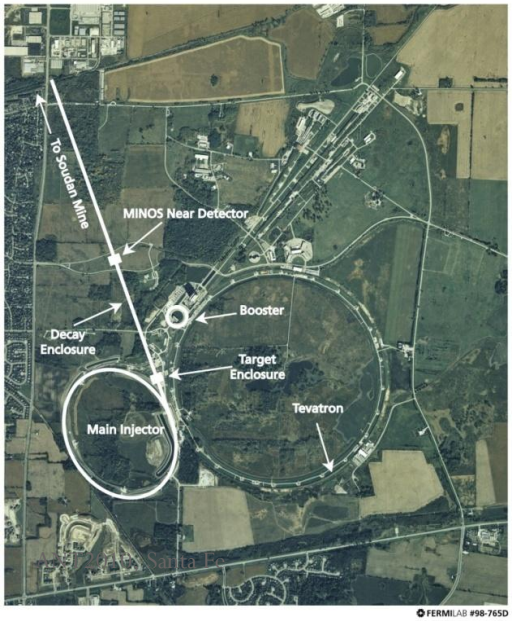
- Fiber
- Scintillator
- PVC extrusions
- Detector modules
- Module assembly
- Photodetector

Other important

- **Buildings**
- **Software**
- **Beam**
- **Schedule to Data Taking**
- **Electronics**
- **Data Acquisition (DAQ)**

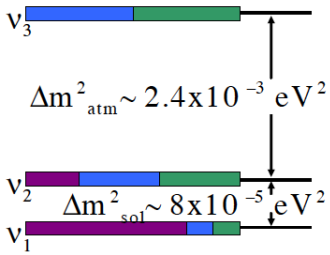
NOvA experiment

- 2nd generation long baseline
- Use existing high intensity beam of muon neutrinos at Fermilab.
  - Construct two detectors off the main axis of the beam.
  - Location reduces background for the search.
- If neutrinos oscillate, electron neutrinos are observed at the Far Detector in Ash River, 810 km away.



NOvA goals

The atmospheric mass scale: Δm^2_{32}.
Large mixing angle for atmospheric neutrino oscillations: θ_{23}.
The third mixing angle: θ_{13}.
CP violation: δ_{CP}.
Mass ordering for the atmospheric oscillations: the sign of Δm^2_{32}.



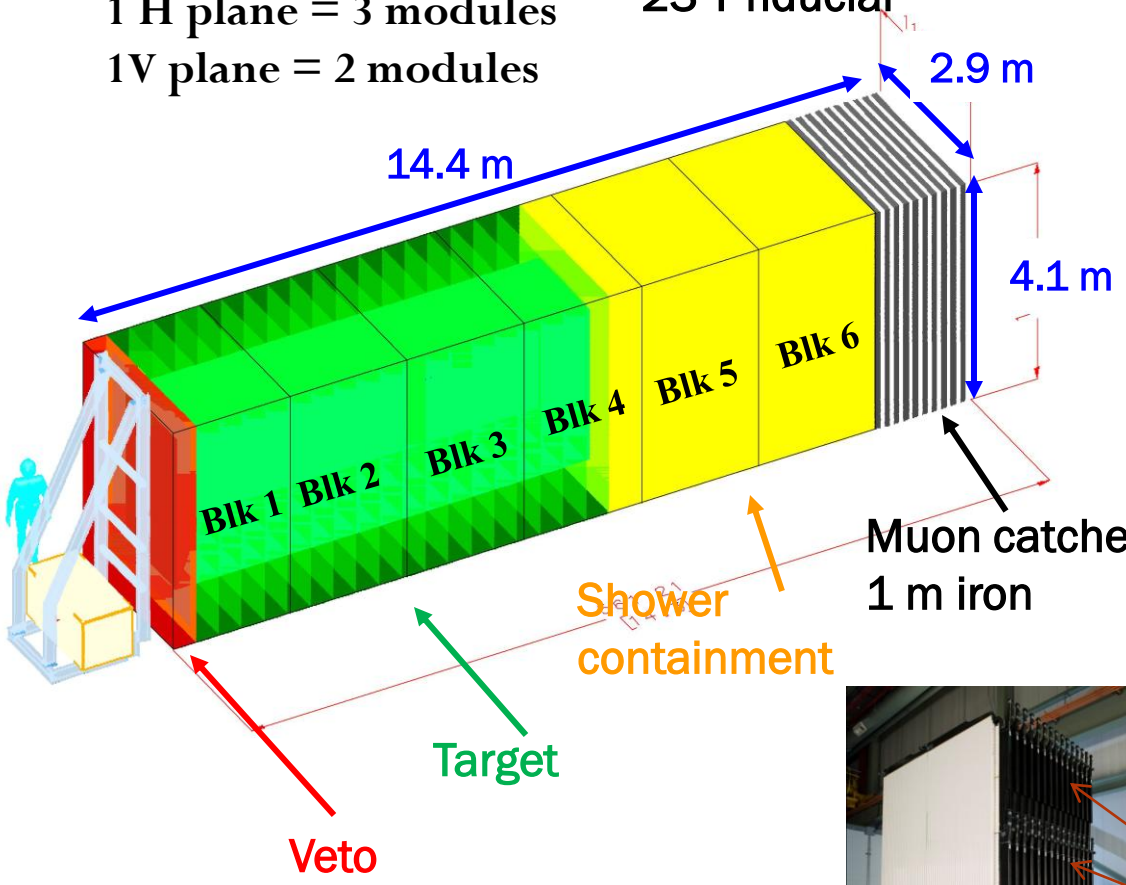
Near Detector

Near Detector prototype built on the surface in NUMI off-axis beam.
Runs for ~1 yr

209 T
126 T totally active
23 T fiducial

Near detector put in the NUMI beam tunnel off axis.

1 blk - 78 modules
1 H plane = 3 modules
1V plane = 2 modules

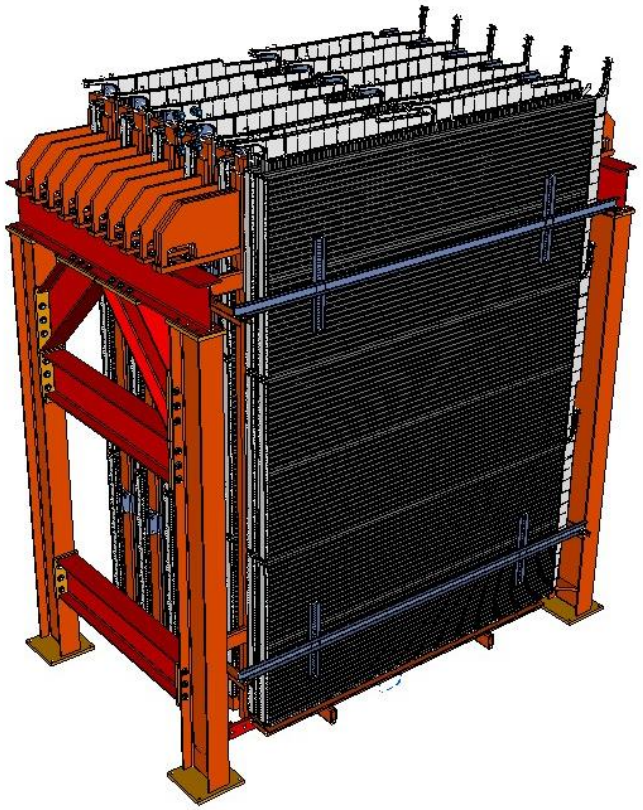


3 H modules

2 V modules

Near Detector μ Catcher

- The Near Detector is backed up by 1 meter of steel, with standard modules interleaved.
- The μ Catcher is now completely designed
  - Will be installed in the NDSB
  - Steel deliveries have delayed construction

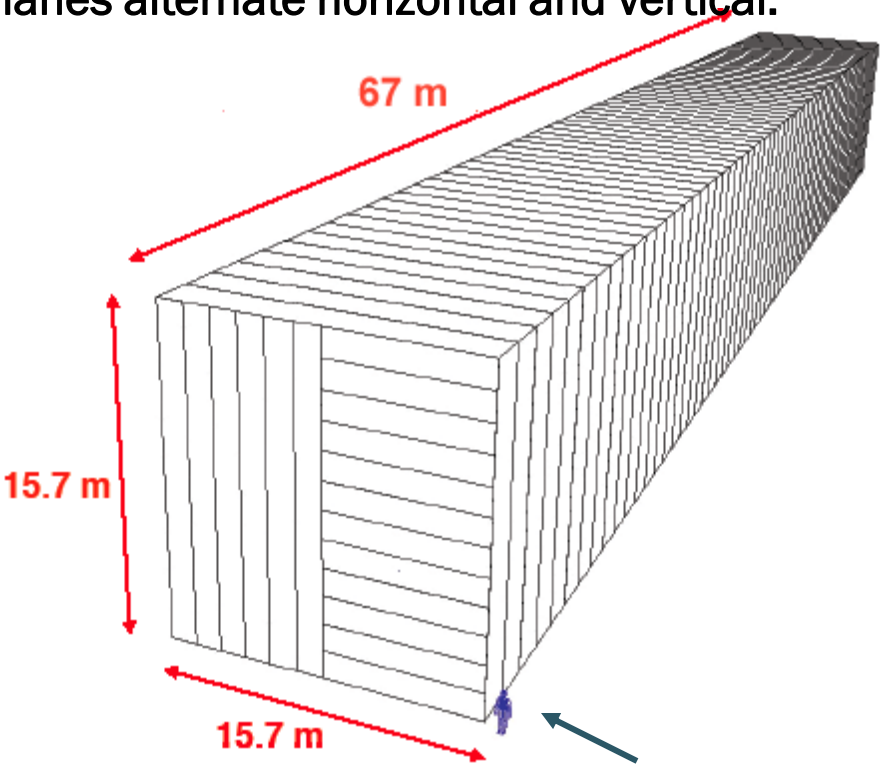


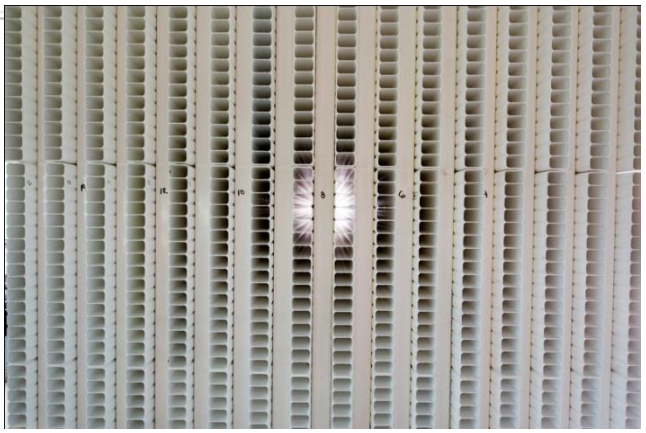
- 10 layers steel, module
  - Last layer has 4 modules

Far Detector

1000 planes , 380,000 channels
15 kT mass (~85% fudicial)

- Cells are in 16-cell PVC extrusion.
- Glue 2 extrusions together to make a 32 cell module.
- 12 modules make up a plane.
- Planes alternate horizontal and vertical.

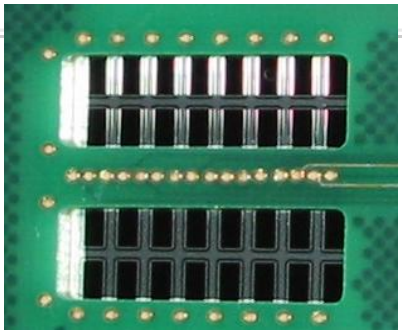


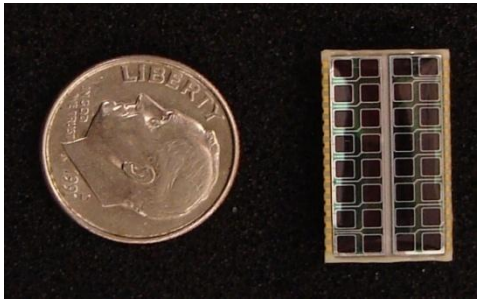


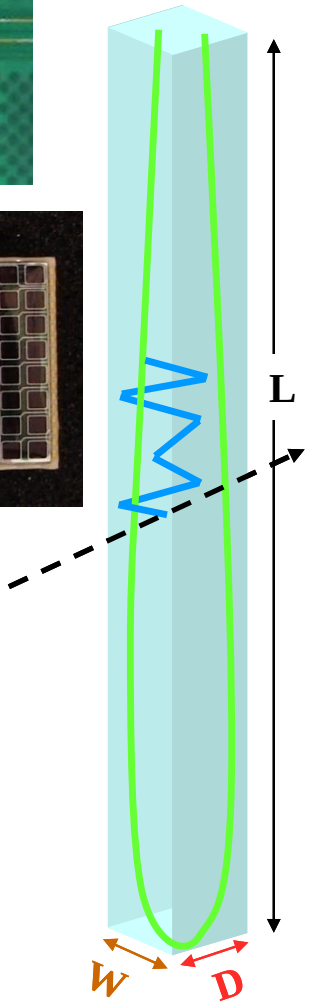
Extrusion cells in the near detector protoblock

Detector Components

- Liquid scintillator (3 million gallons)
  - Contained in 3.9cm x 6.6 cm cells of length 15.6 meters
  - 3.9 cm as seen by the beam
- Cell walls are rigid PVC (5 kilotons)
  - Loaded with 15% anatase form of titanium dioxide
  - Diffuse reflection at walls keeps light near (within ~ 1 m) particle path
- Looped wavelength-shifting fiber collects light (11,160 km)
  - Fiber diameter 0.7 mm
  - Fiber shifts wavelength to ~ 520-550 nm along the fiber
- Avalanche photodiode (APD) converts light to electrical signal (11,160 devices, ea. 32 pixels)
  - 85% quantum efficiency







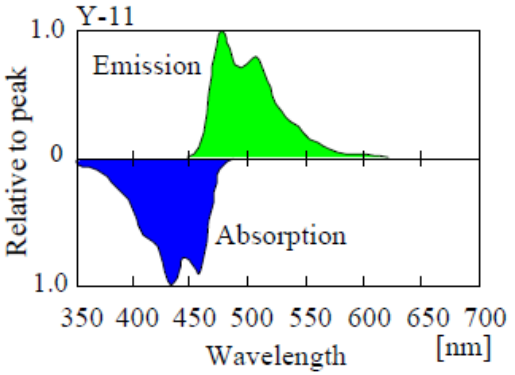
Liquid Scintillator Composition

- Liquid scintillator for NOvA is composed of a primary scintillant (pseudocumene) that gives off light at 300 nm,
- waveshifters (PPO & bis-MSB) that downshift the UV photons to longer wavelength to facilitate absorption by the wavelength shifting (WLS) fibers (convert the photons to 420 nm),
- anti-static agent (Stadis) that prevents the build-up of static electricity.
- The "fluor mix" + anti-static are dissolved in a mineral oil solvent

	component		mass fraction
solvent	*mineral oil*	liquid	94.90%
fluor mix	*pseudocumene*	liquid	4.99%
fluor mix	*PPO*	powder	0.110%
fluor mix	*bis-MSB*	powder	0.0015%
anti-static agent	*Stadis-425*	liquid	0.0010%
	Total		100.0%

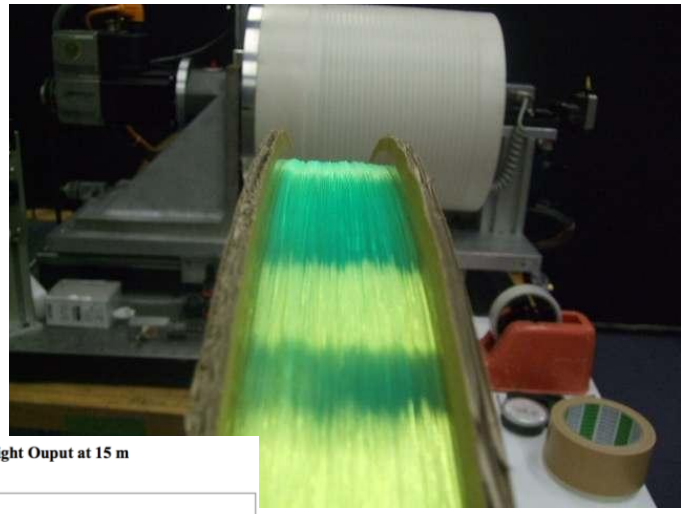
WSL Fiber

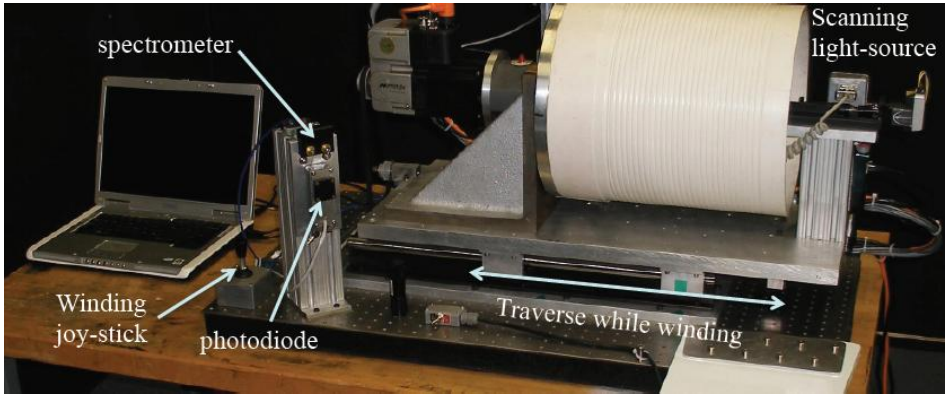
Need ~ 12,000 km of 0.7 mm diameter wavelength shifting fiber from Kuraray. So far ~10% received and tested

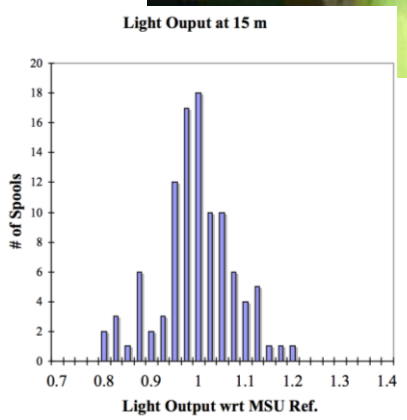


K27 dye @ 300 ppm, S-type

- MSU Quality Assurance Scanner (duplicate at Kuraray factory)
  - Fiber wound on a drum in a 27 m long groove with holes on 1 m intervals
  - Fiber is NOT cut from the spool,
  - Light source illuminates fiber from within the drum
  - Total light output (photodiode) and spectrographic scans, each ~ 1 minute







Michigan State

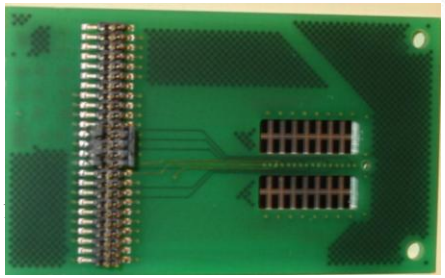
APD Description

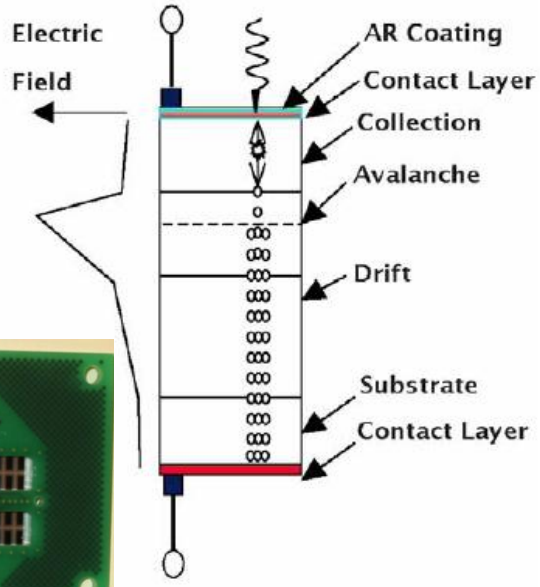
- APD is a classic linear APD manufactured by Hamamatsu operated at a gain (M) of 100
  - S11211(X) custom variant of commercial S8550 SiAPD
- Operating temperature is -15°C to keep shot noise at the same level as the amplifier noise
- Signal-to-noise > 10 for muon at far end of a 15m long cell
- Both ends of the fibers

in each cell are read with a single APD

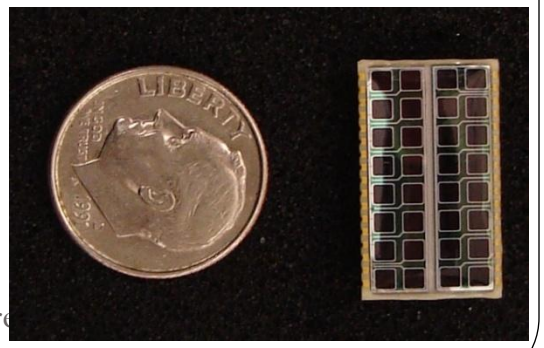
- 32 APDs in a single

4 × 8 array to readout one module

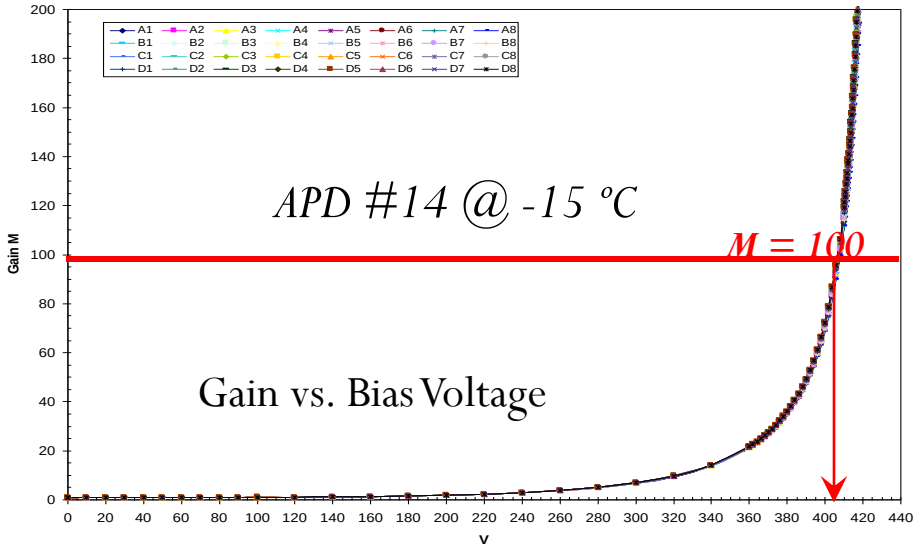


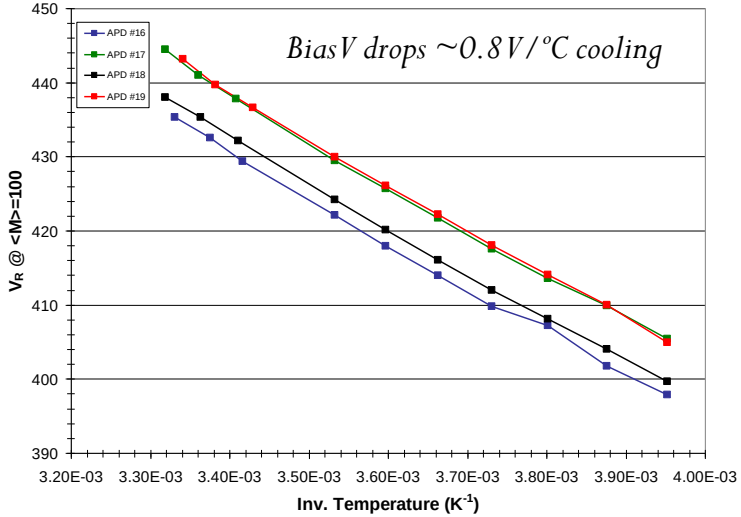


Manufacturer	
Pixel Active Area	1.95 mm × 1.0 mm
Pixel Pitch	2.65 mm
Array Size	32 pixels
Die Size	15.34mm × 13.64mm
Quantum Efficiency (>525 nm)	85%
Pixel Capacitance	10 pF
Bulk Dark Current (I_B) at 25 C	12.5 pA
Bulk Dark Current (I_B) at -15 C	0.25 pA
Peak Sensitivity	600 nm
Operating Voltage	375 ± 50 volts
Gain at Operating Voltage	100
Operating Temperature (with Thermo-Electric Cooler)	-15°C
Expected Signal-to-Noise Ratio (Muon at Far End of Cell)	10:1
APD channels per plane	384
APD arrays per plane	12
Total number of planes	930
Total Number of APD arrays	11,160
APD pixels total	357,120

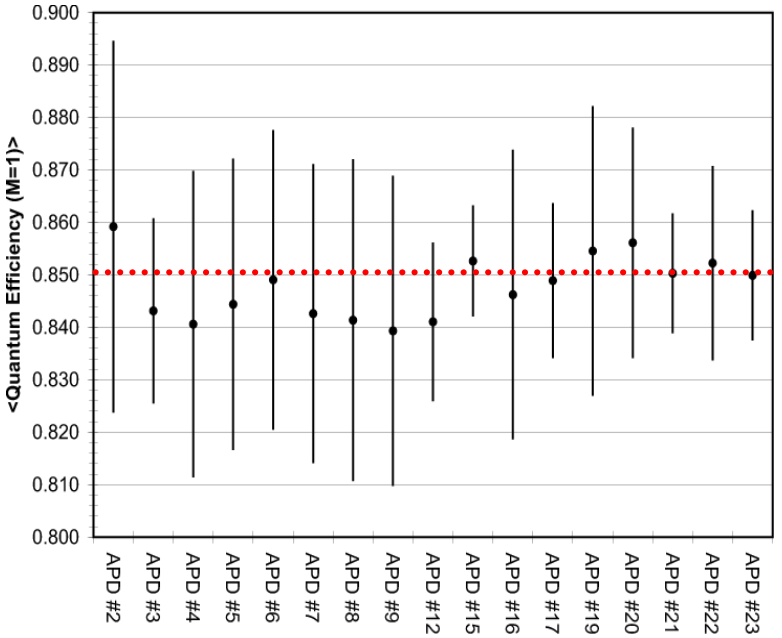


Tests of APDs





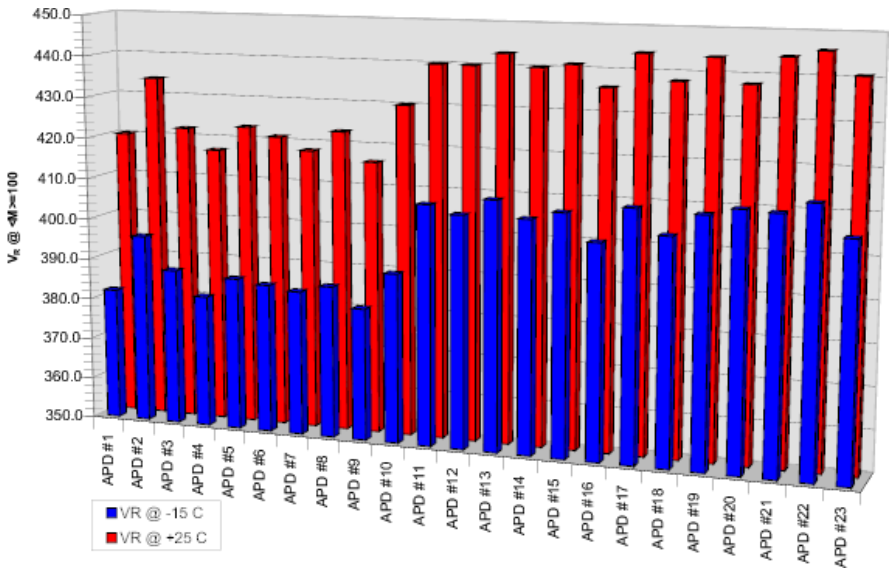
Gain=100 bias voltage *linear* vs. temperature



- Measured average QE with RMS spread across 32 channels
- Average across all channels (84.8 ± 2.5)% – expected 85%

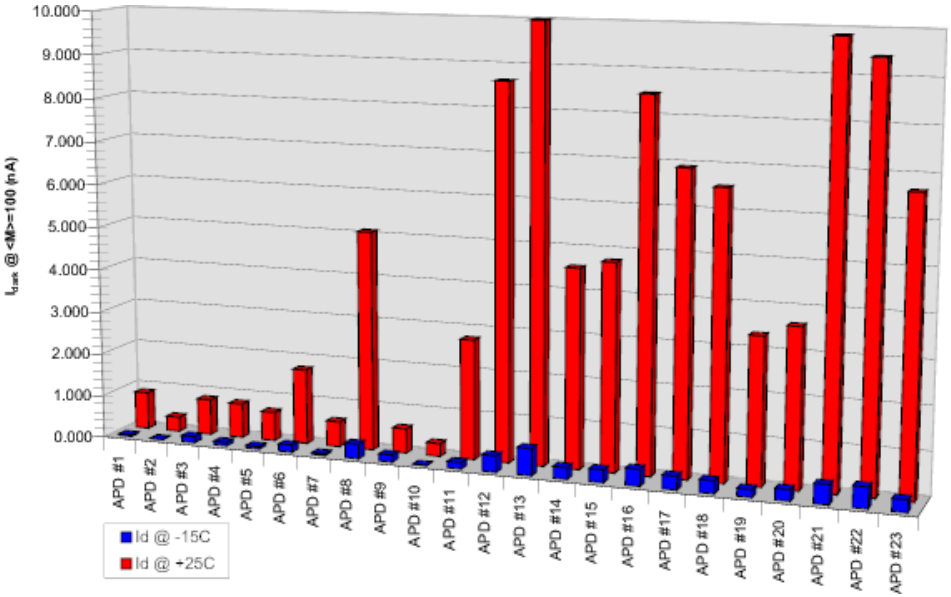
APD tests

Bias V for Gain = 100



- Bias voltage ~40 V lower at –15 °C than +25 °C
- Batch 1 APDs bias voltage lower than batch 2

Average Dark Current

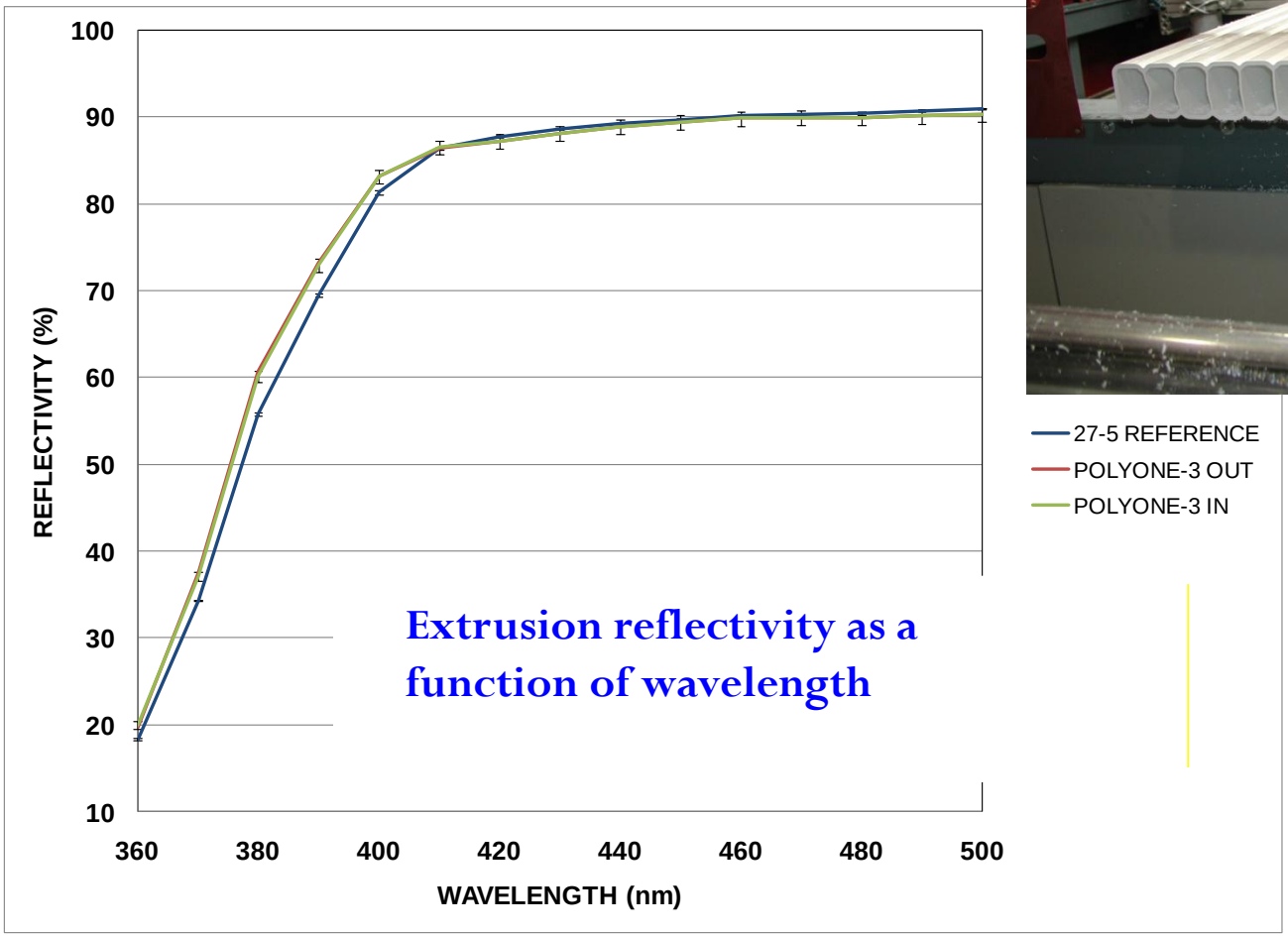


- Average dark current ~20x lower at –15 °C than +25 °C
- Batch 1 APDs average dark current ~10x lower than batch 2

Dark current at room temp about 0.2na (40x better than specification)

PVC Extrusions

15% Anatase titanium dioxide



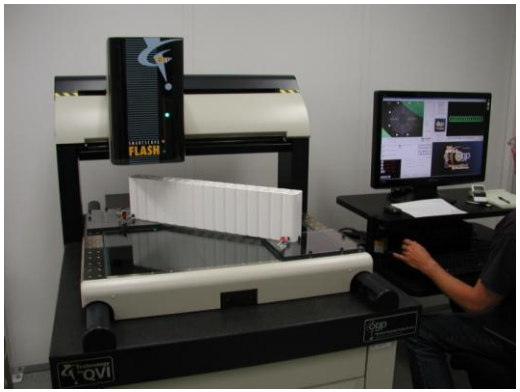
Extrusion reflectivity as a function of wavelength

- All NDOS extrusions produced.
- Retooling for far detector extrusions (430 kg/hr)
- Production started in August 2010

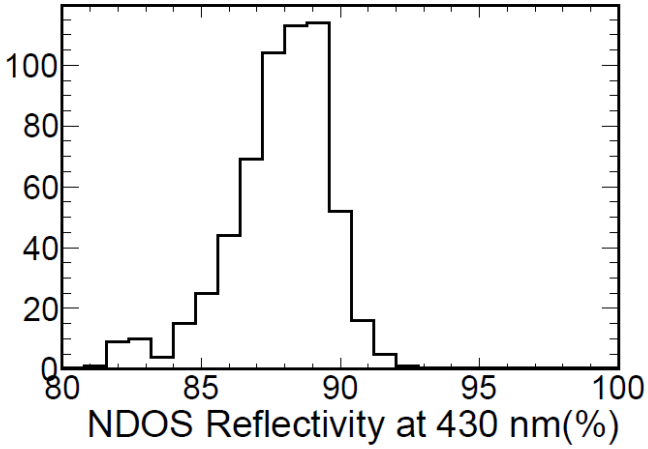
Argonne & Fermilab

Technical details

- N-27 PVC Resin Compounder Contract in Place
  - PolyOne Corporation (Different than R&D Vendor Aurora Plastics)
  - Material has been tested and meets NOvA specification
- Extruding Vendor Contract in Place
  - Extrutech Plastics, Inc
  - Construction Dies and Tooling have been delivered
    - Tuning and testing since April
  - Expect die tuning to be completed in Sept. 2010

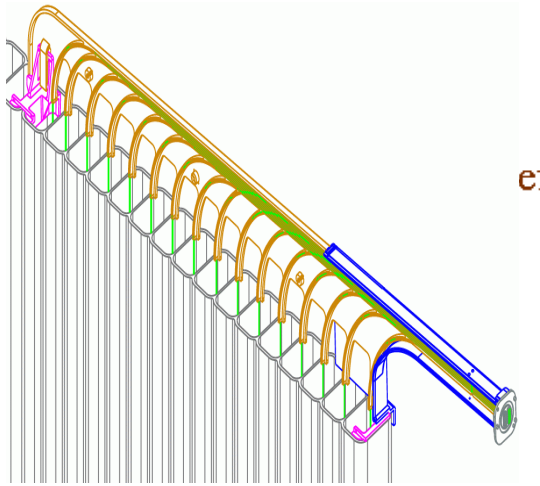


- Dimensions: Optical Metrology Machine
  - Flatness, Thickness and Shape
- Continuity of cell webs: Vacuum test
  - Alternate cells are placed under vacuum and others are at room pressure
- Structural and Material Strength
  - Test short (6") extruded samples
  - **Hydraulic pressure test** to failure (~150 psi)
    - Alternate cells pressurized
  - Drop-dart Impact test to measure of PVC ductility
- Reflectivity: Spectrophotometer
  - Measures reflectivity across scintillation spectrum
    - MC computes relative light output of module



Module Architecture

end plate

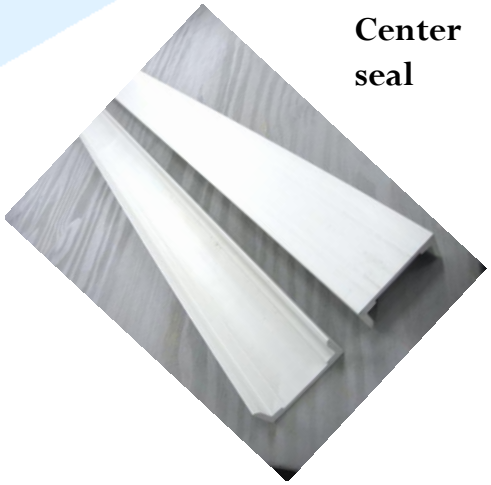


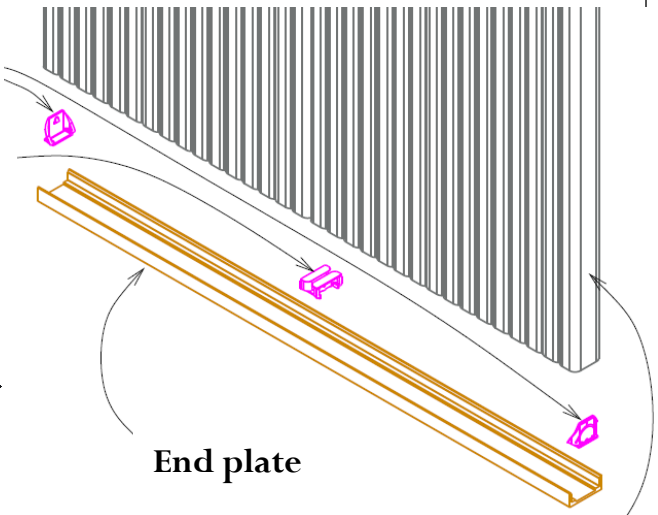
extrusion assembly

manifold

Side seals

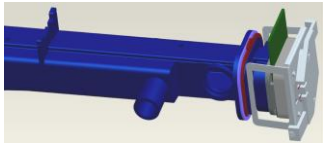
Center seal



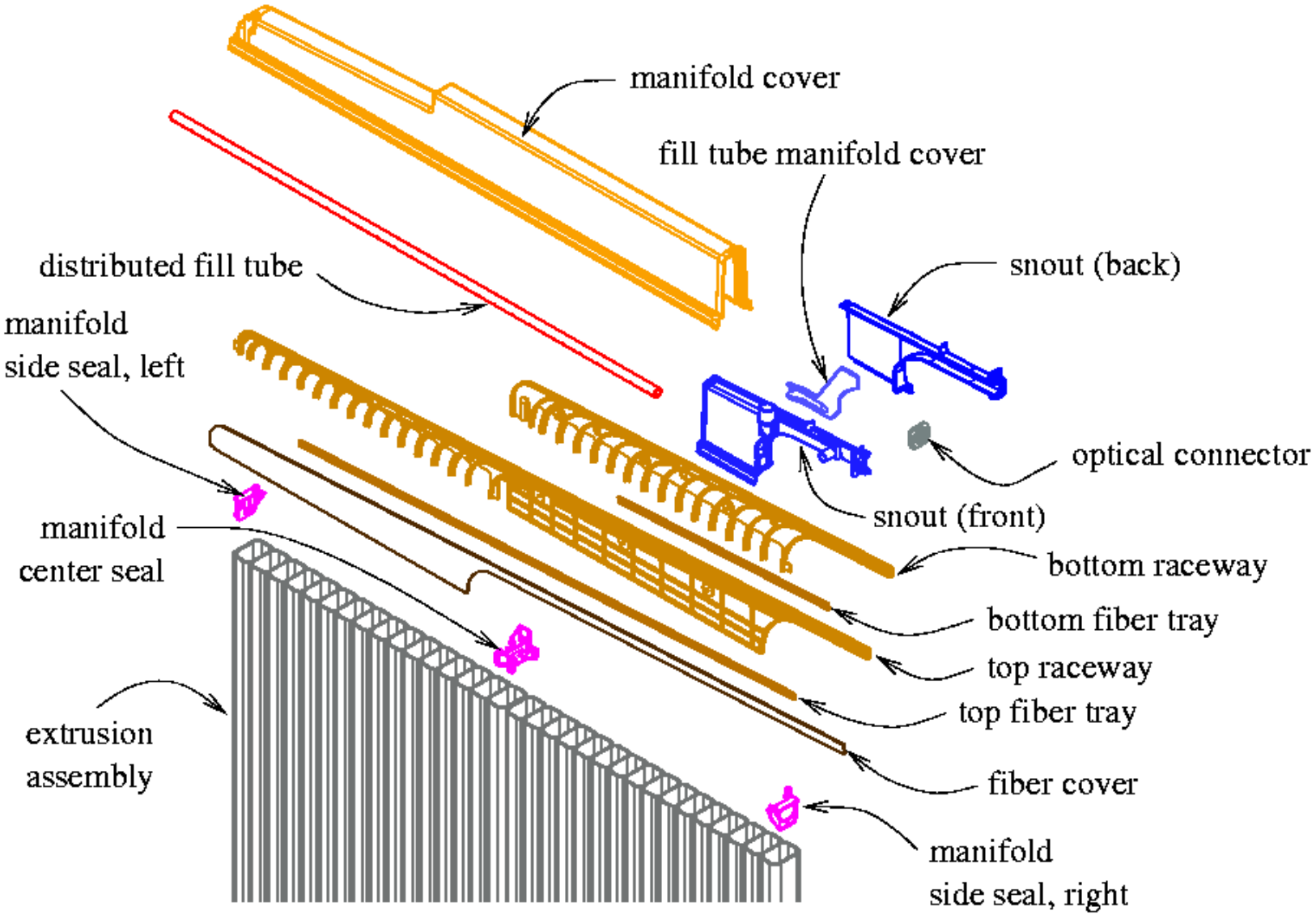


End plate

Extrusion assembly



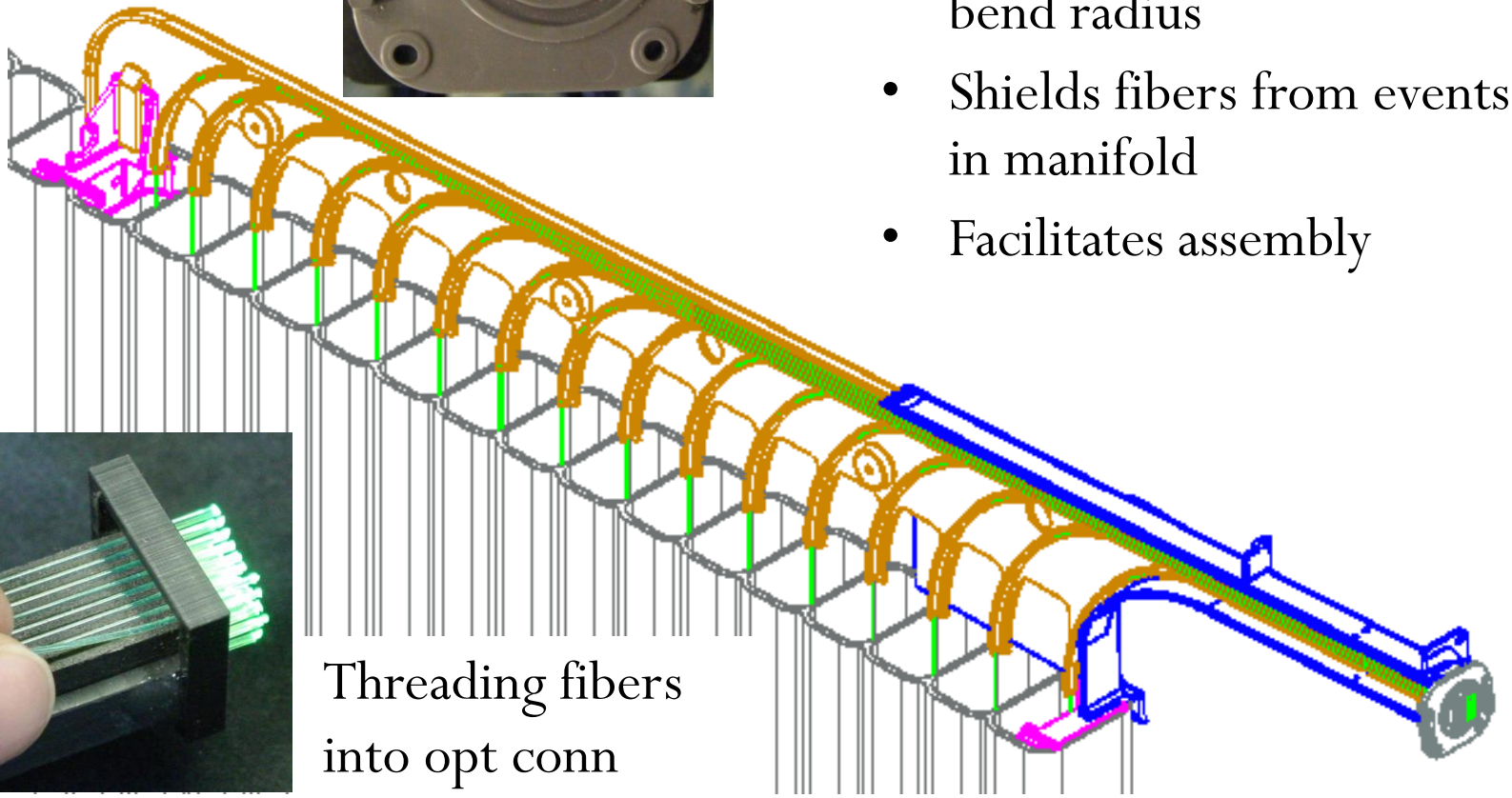
ND Manifold Architecture



Raceway Functionality

Face of optical connector

- Registers fibers in optical connector
- Guarantees acceptable bend radius
- Shields fibers from events in manifold
- Facilitates assembly

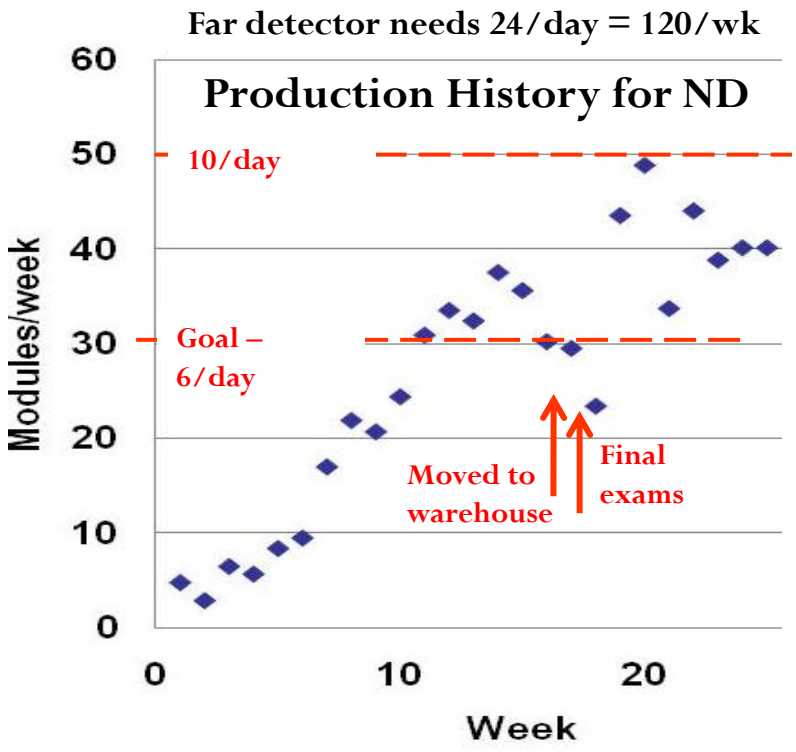


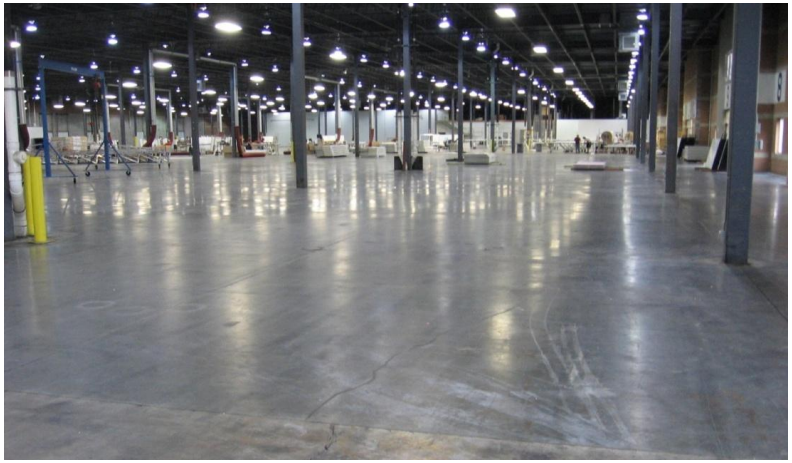
Threading fibers into opt conn

Production Factory

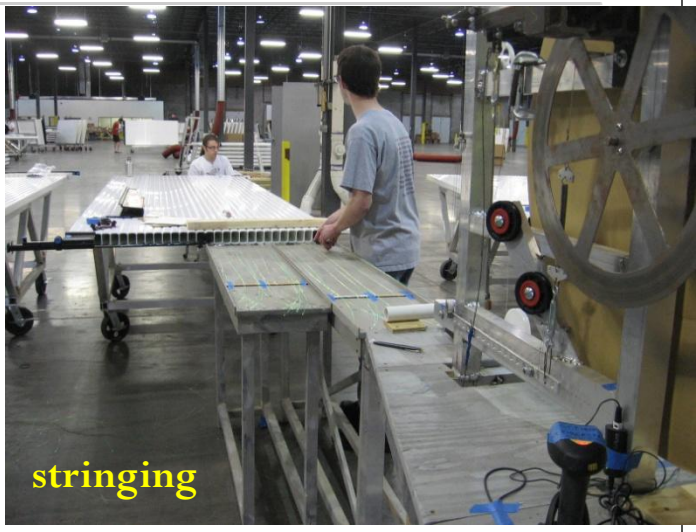
A Huge warehouse for module production and storage for both extrusions and modules.

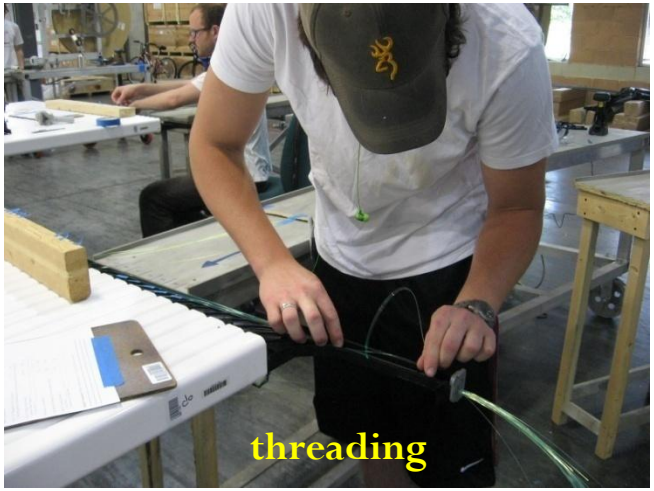
Production is based on student labor.

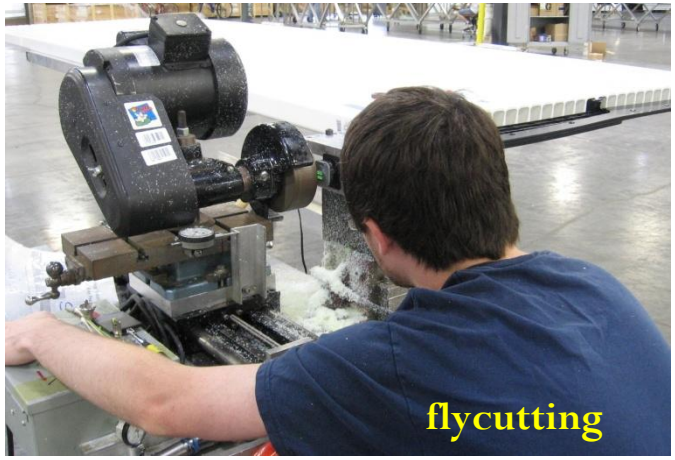


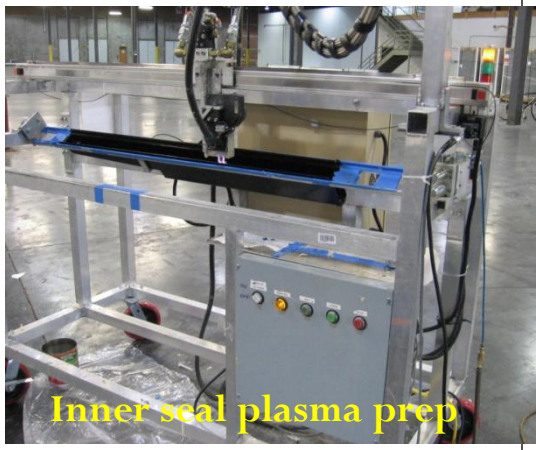


Module Construction Process









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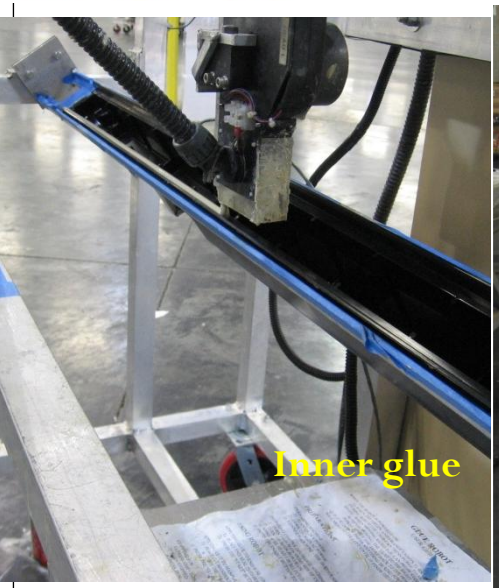
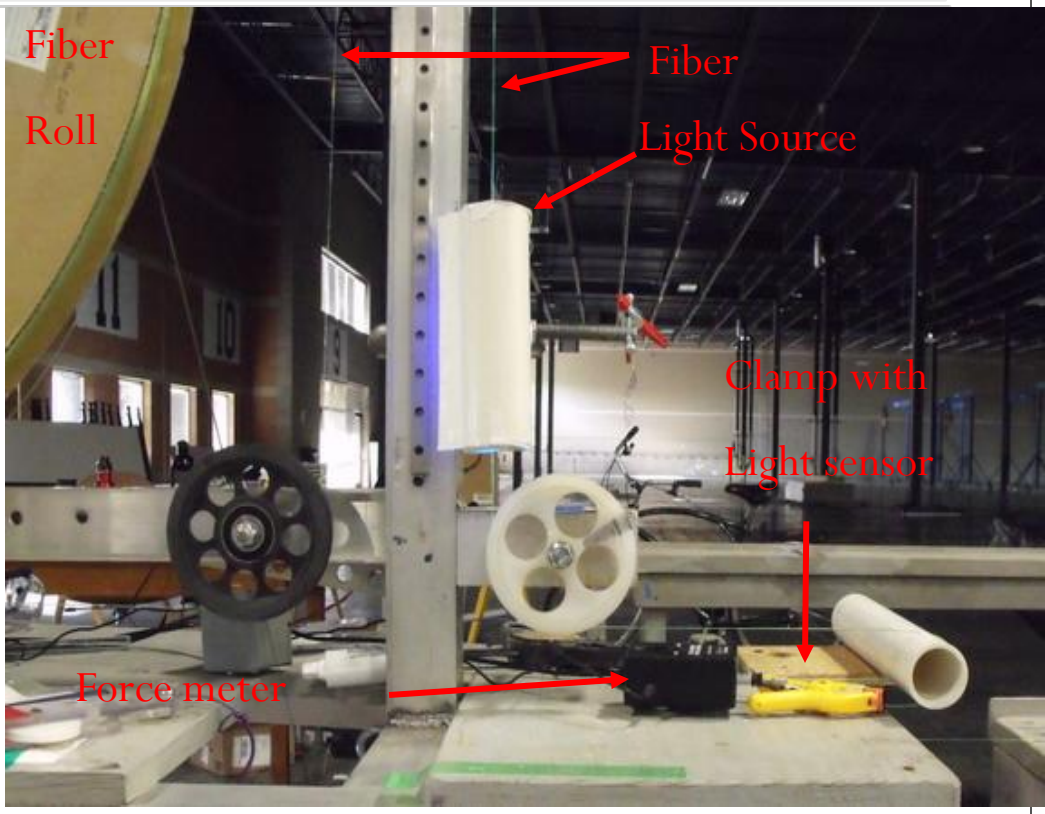
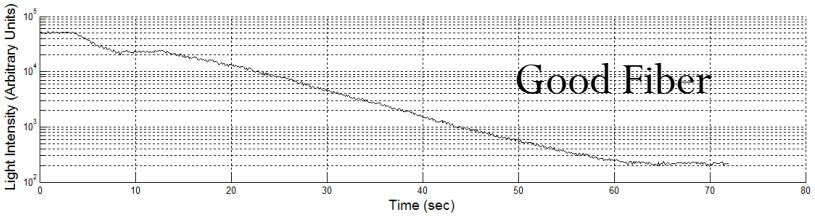
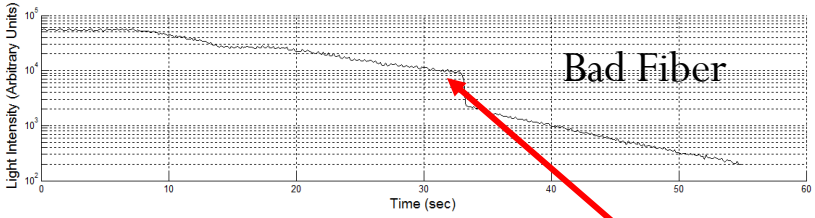


Monitoring Fiber While Stringing

- Monitors fiber tension and light transmission as cells are strung
- Components
  - Light source
    - PVC tube with blue LEDs
    - Blinks at 10 Hz
  - Photodiode light sensor
  - Force meter



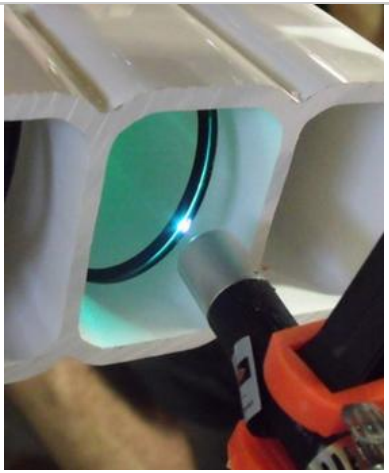


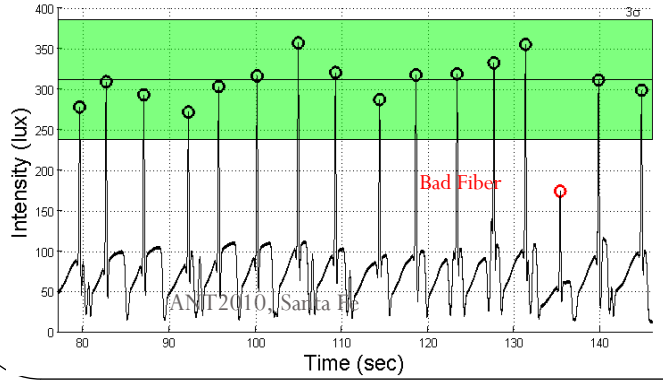


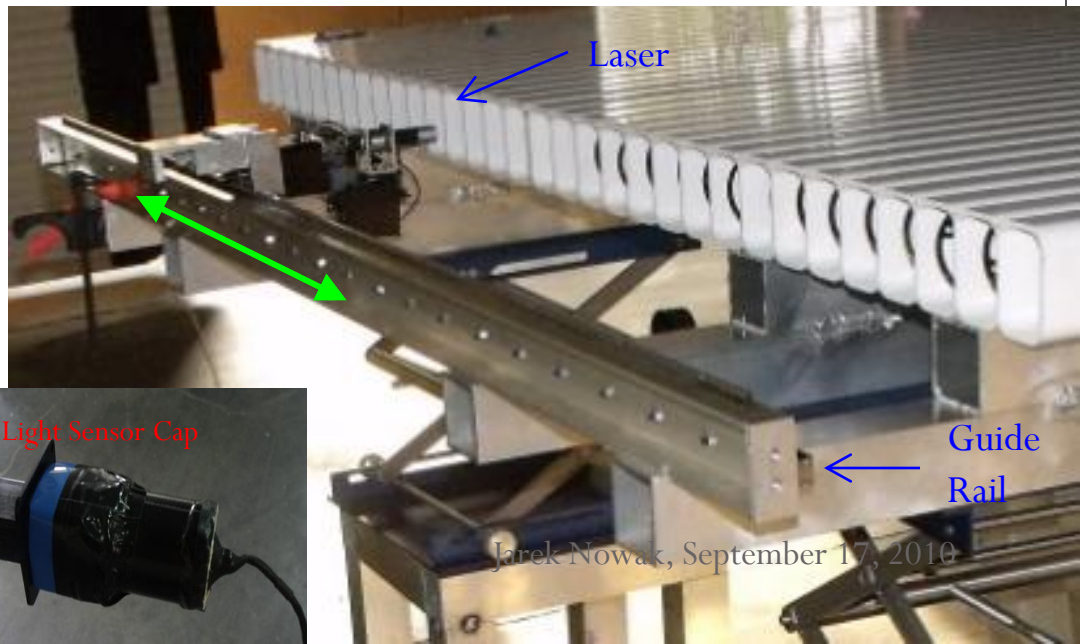
John Kwong
UMN

End-Lit Fiber Tester

- Measures light transmission of threaded fibers
  - Bad fibers can be replaced (fibers not yet glued into optical connector)
  - Light is injected with blue laser and light is measured at the optical connector
  - Injection is highly localized and uniform across cells
  - Scan time = 40 seconds for 32 fibers
  - Fiber exposed to laser for ~0.5 seconds
    - Long exposure tests indicate no damage
- Components
  - 10 mW blue laser
  - Robot that moves the laser
  - Photodiode light sensor
  - Hot wire fiber cutter

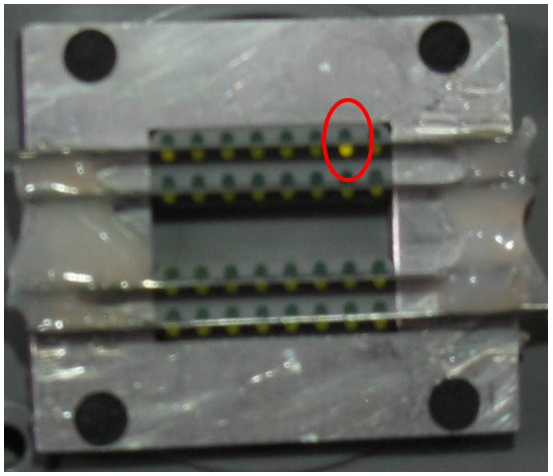




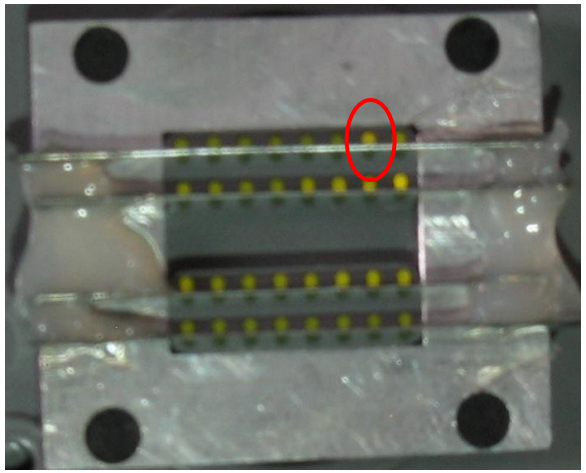


Types of Photos

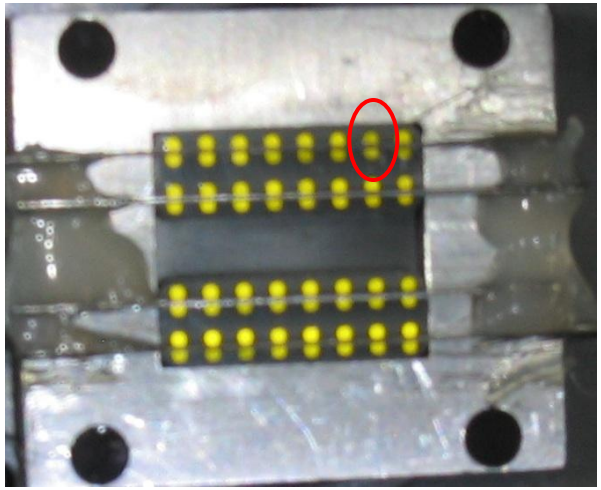
1 - Top Lit

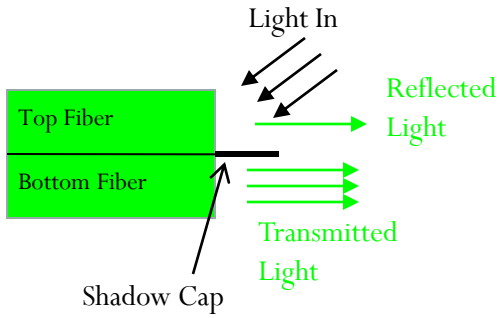


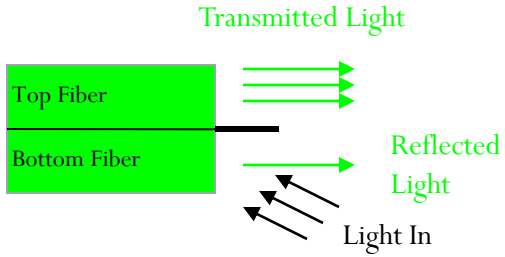
2 - Bottom Lit

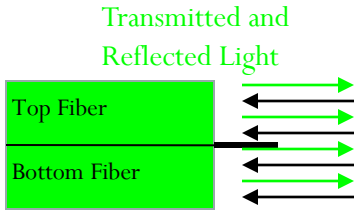


3 - Center Lit (normal angle)





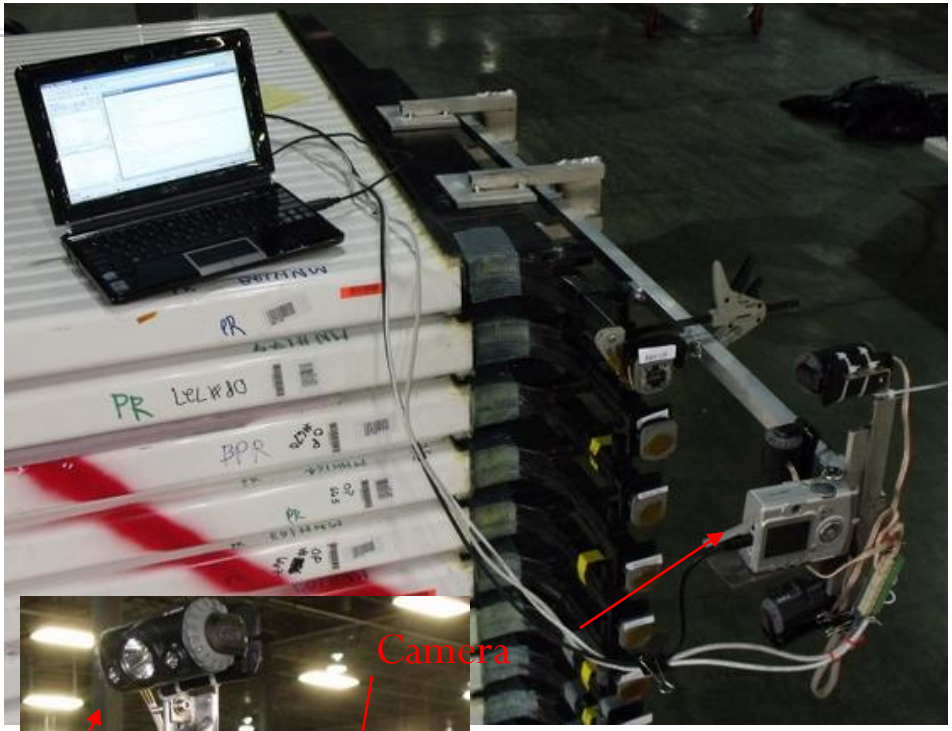




- Defects found by catching abnormal intensity of
  - Reflected light of angled light photos (1 & 2)
  - Transmitted light of angled light photos (1 & 2)
  - Light of normal angle light photo (3)

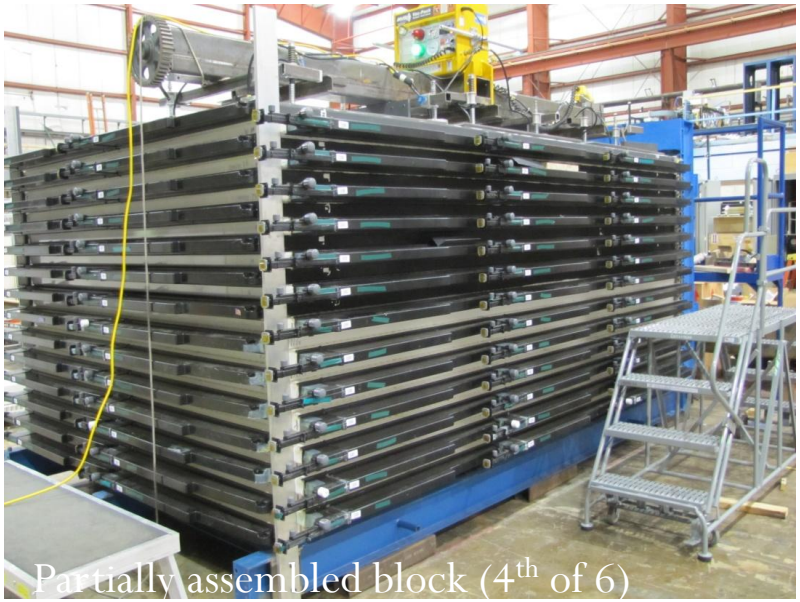
Closed Module Tester

- To be used for final QA at factory and after arrival at far detector site
- Shine light on fiber ends and measure output intensity with a camera
- Components
  - Digital camera
  - Three LED lights
  - Shadow cap

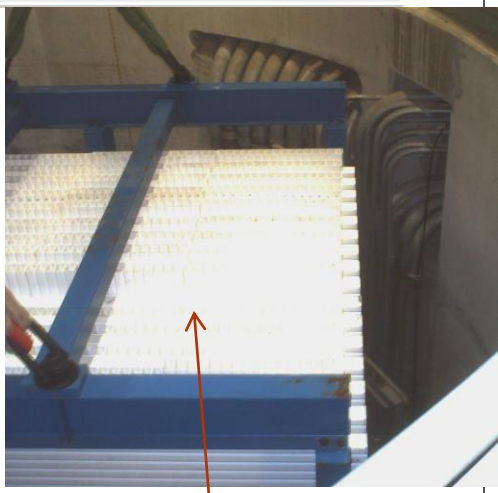


Near Detector Assembly

- Prototype Near Detector blocks have been assembled at ANL since April
- Five blocks are at FNAL, in position.
- Construction of the 6th will begin soon.



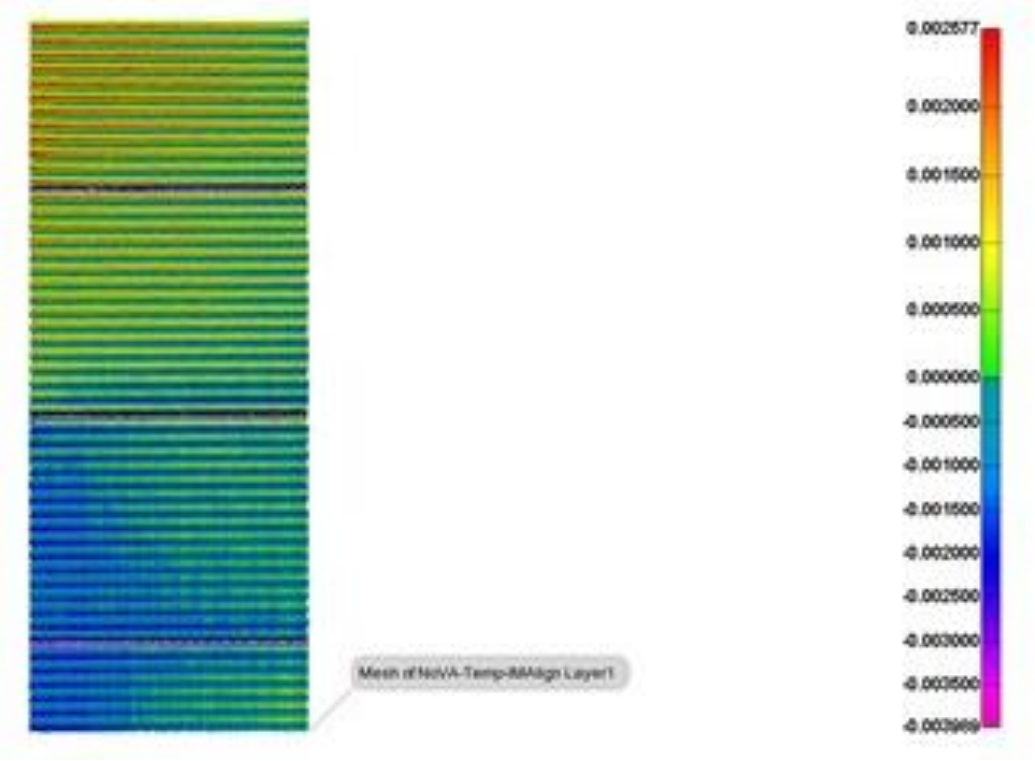
- Partially assembled block (4th of 6)



- Constructed at Argonne
- Raised in the MINOS service building
- The first mechanical prototype block (protoblock)

Lowering the protoblock into the MINOS shaft at FNAL

Prototype Alignment



Scanner maps surface, multiple measurements

- One face of the protoblock, laser scanner test
  - This will be typical of the blocks - ~2.5 mm range
  - The contour of both faces track each other.

Summary

- 5 out of 6 blocks of the Near Detector are installed.
- The Integration Prototype Near Detector is extremely useful.
- Filling with liquid scintillator will start within a few weeks.
- The near detector will start taking data in November.
- The far detector production is on the schedule.