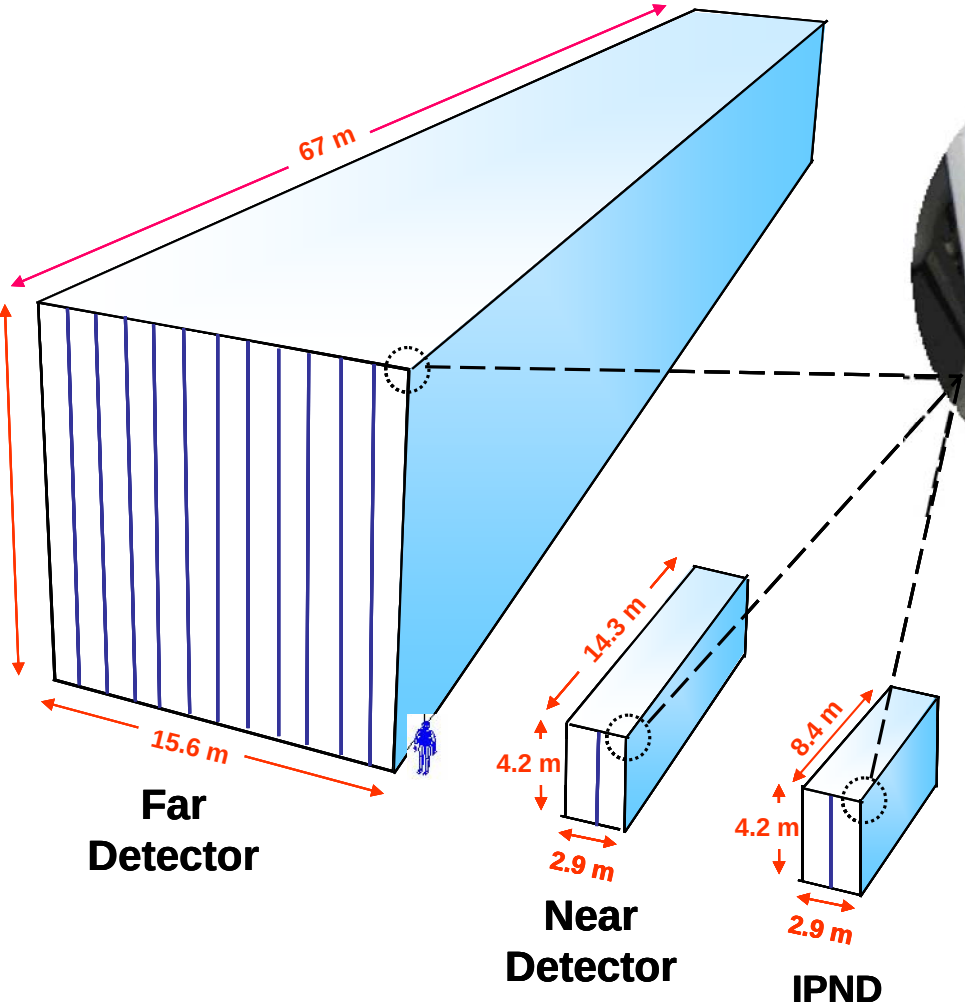
NOνA PVC Extrusions and Detector Assembly

Richard Talaga, ANL

September 24, 2009

DOE Site Visit

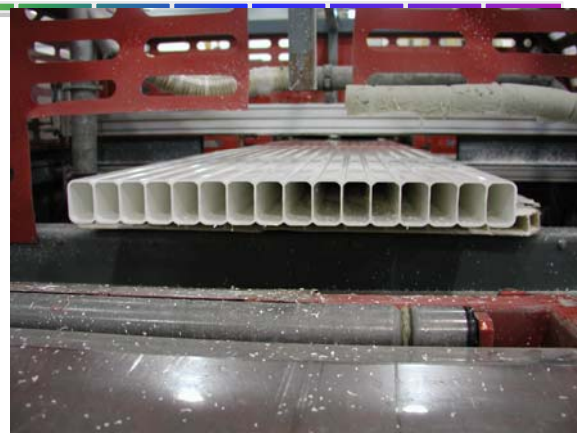
NOvA Detectors



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

- **Far Detector**
  - 12 by 12 extrusion modules
  - 930 layers
- **Near Detector**
  - 2 by 3 extrusion modules
  - 206 layers
  - Will be 300 feet underground at Fermilab
- **Integration Prototype Near Detector**
  - 2 by 3 extrusion modules
  - 124 layers, reuse all in Near Detector
  - **Now building all 222 tons, reusing all**
  - Will be on the surface at Fermilab

PVC Extrusion in NOvA



- Scintillation Light Reflectors
  - Optimized for high reflectivity
- Structural Elements of NOvA Detectors
  - Optimized for mechanical strength and integrity
    - Liquid Scintillator Containers
    - Basic structural elements

Argonne Tasks

Richard Talaga

- L2 Manager: Overall responsibility for PVC extrusions
  - Formulation, Extruding, Shipping, Contracts
- Cost Account Manager (CAM): $26.6 M budget
  - Trained in EVMS, passed EVMS Fermilab Review
- NOνA Collaboration Responsibilities
  - Technical Board
  - Executive Committee
- ANL NOνA Detector Assembly Group
  - Physicist in charge (replaced Dave Ayres ~ one year ago)
  - Tasks
    - Assembly Machinery (gluing, vacuum lifting)
    - FSAP & FHEP prototype assembly
    - Near Detector (IP/ND) assembly

Argonne Tasks

Jim Grudzinski

Mechanical Engineer, NE Division (formerly HEP)

- L3 Manager
  - PVC formulation & mechanical properties
  - Quality Control & Assurance
- **Vic Guarino,** HEP
  - Mechanical Support Group Leader
  - NOνA Assembly L3 manager
    - Assembly equipment: Glue machine, vacuum lifter, etc.
- **Allen Zhao**, HEP Engineer
  - Prototype mechanical tests

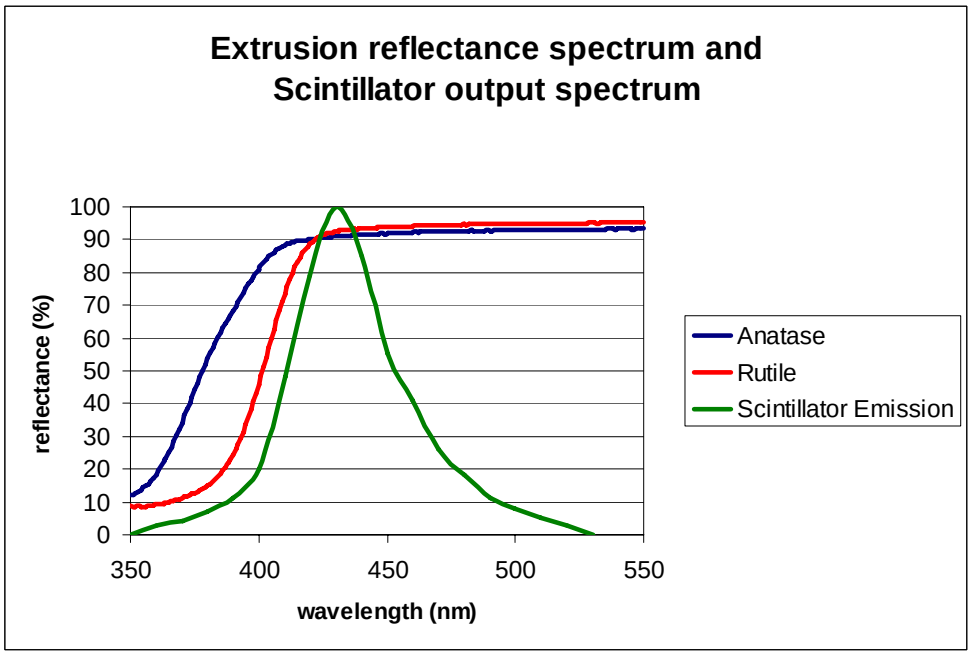
Resin and Extruding

- R & D 2005-2009
  - Developed PVC resin formulation: N-27
    - 15% anatase TiO_2
    - Non light-absorbing lubricants and additives
  - Produced extrusions for prototypes & Near Detector
    - Large and complex profile needed much expertise
      - Pushing the limits of extrusion manufacturer's abilities
- Construction 2010-2012
  - Extruder RFP selection process completed August 2009
  - Expect dies and tooling in early 2010
  - Begin production in mid-2010, finish in 2012

PVC Extrusions

1. Purchase ~11 Million lbs of N-27 PVC powder
2. Produce ~ 25,000 extrusions 51feet long
   - Horizontal (thin-wall: 3.3 mm) 12,400
   - Vertical (thick-wall: 4.8 mm) 12,200
   - Also ~25,00 short (6”) extrusions for Quality Control
3. Measure characteristics of extrusions (QC/QA)
   - Optical reflectivity and Bulk Material Properties
   - Precise profile shape and size;
     - Individual Cell Sizes; Wall Thicknesses; Web Thicknesses, etc.
4. Ship PVC Extrusions to Module Assembly Factory
   - Sort Extrusions according to profile height and form a stack
   - Move stacks of extrusions weighing up to 30,000 lbs in and out of trucks

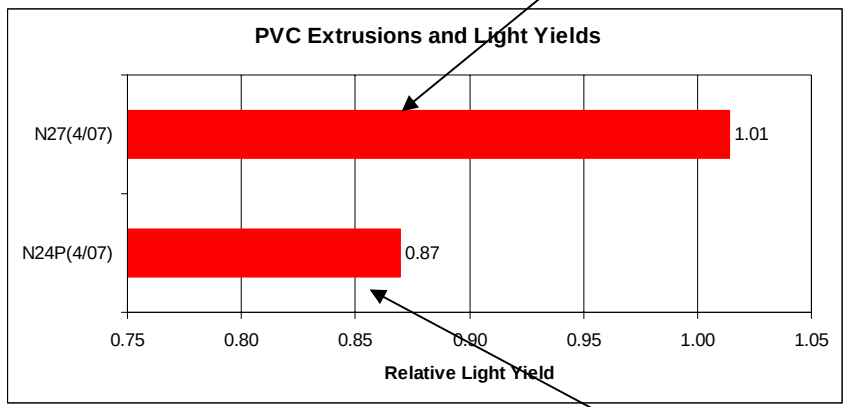
Reflectivity and Light Yield



Reflectance

best NOvA PVC with anatase

N-27



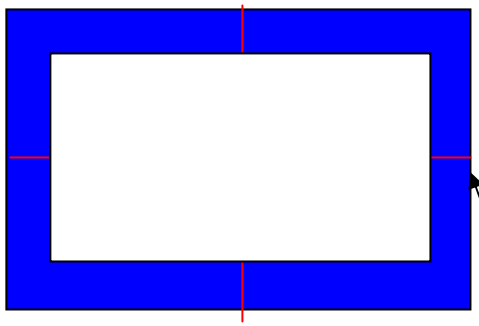
best NOvA PVC with rutile

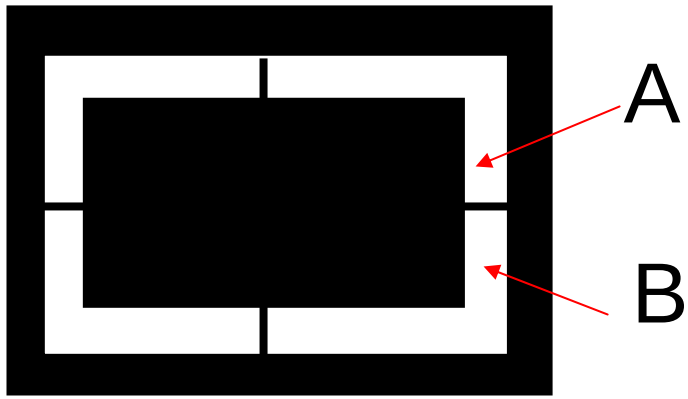
N-24

Light Yield

Example PVC Die: Extrude a Rectangular Tube

Die



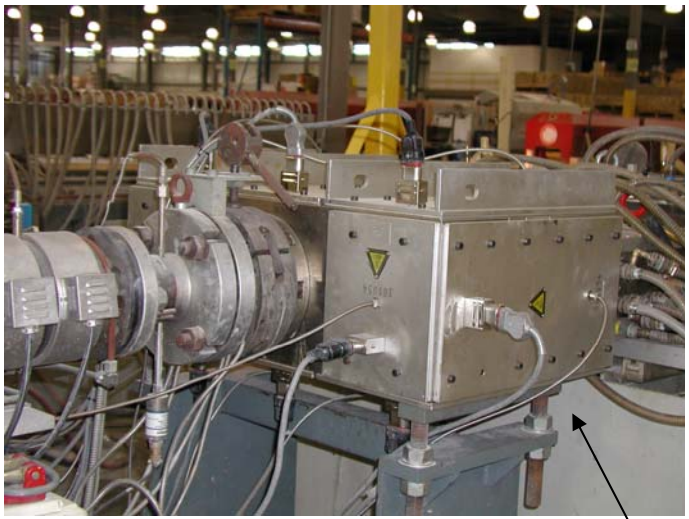


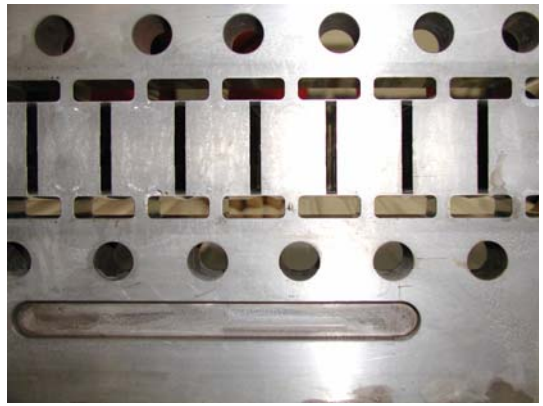
Rectangular PVC tube

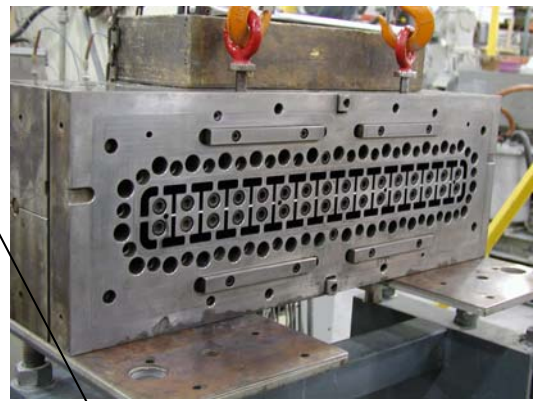
Die Body and Insert, with supports (note: pressure ~3,000 psi requires **strong** supports)

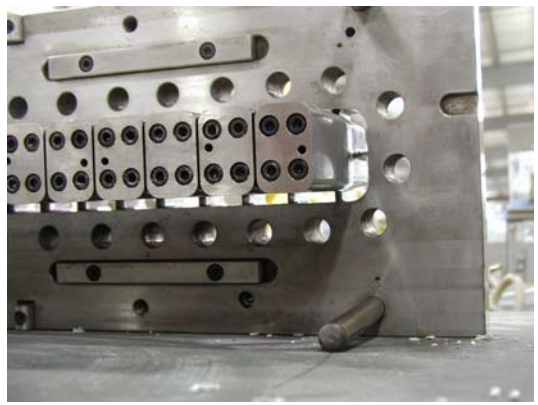
Knitting: Where A and B combine to form a (seamless) junction

NOvA Die: Details









Assembled Die

Extruding Starts with PVC Resin

Automated Feed Mechanism

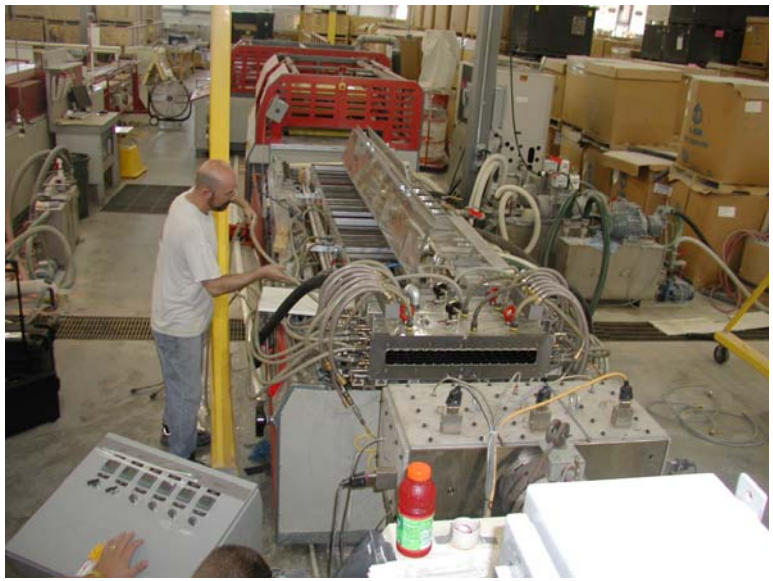
Extruding Machine

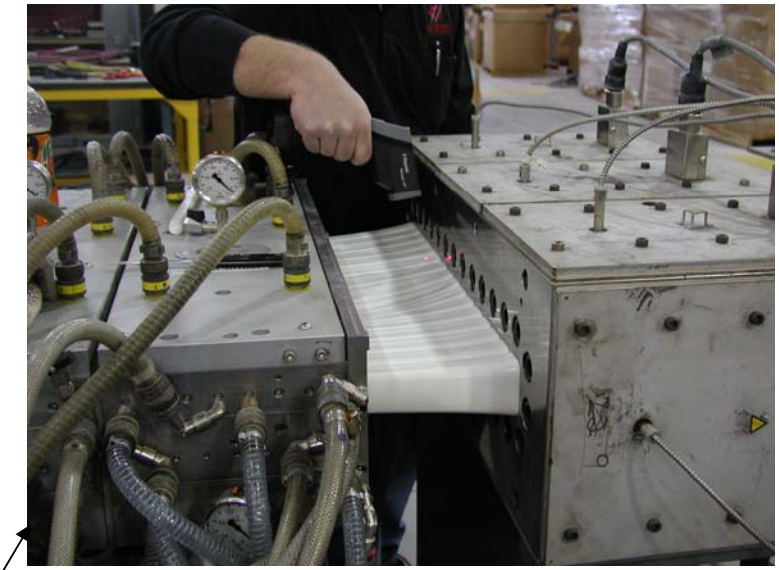
Visual Inspection

Looking for “cottage cheese”

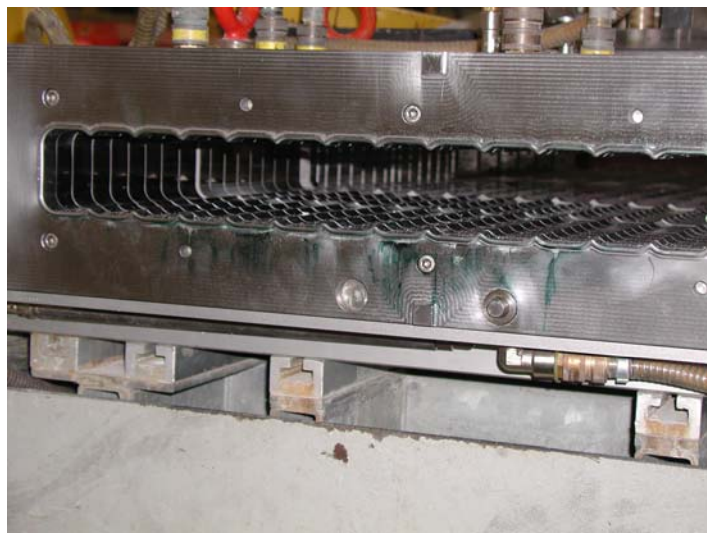
Extruding Line Components

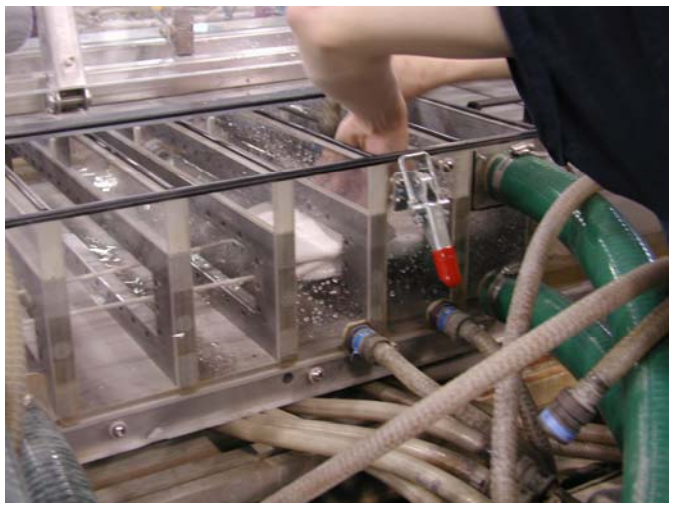
Extruding Line





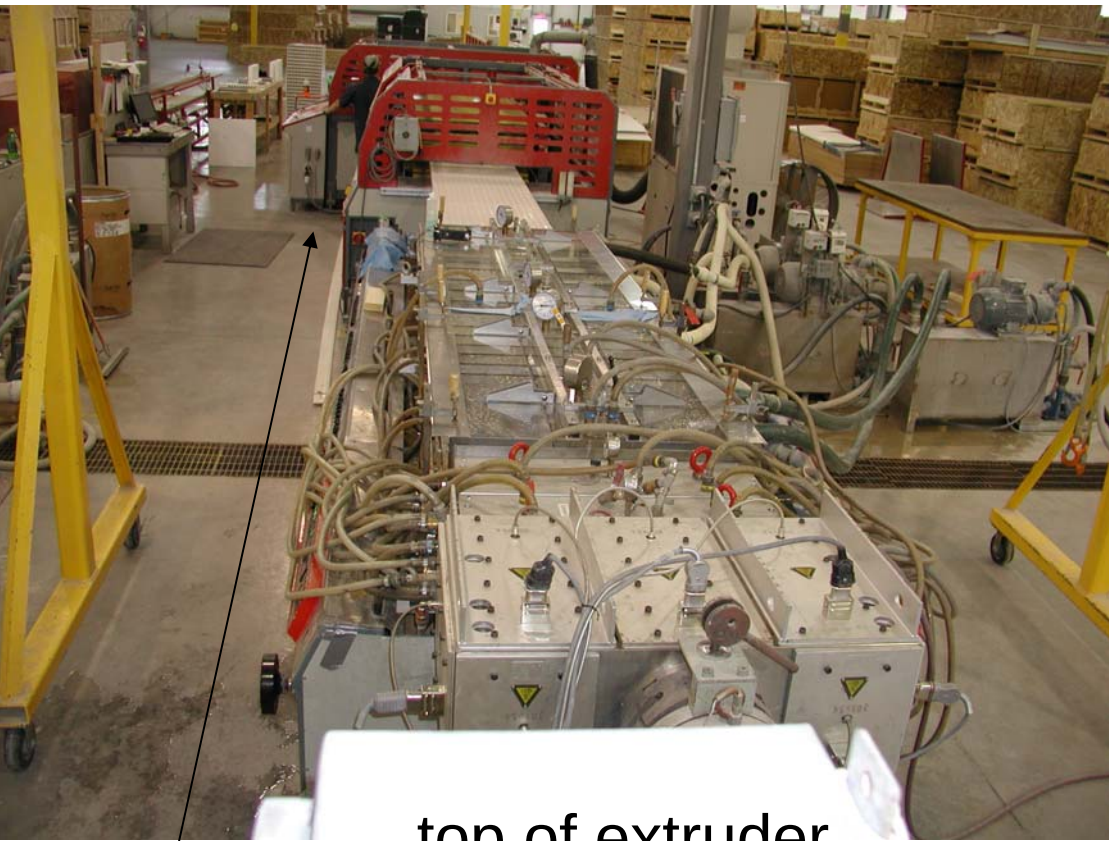
Sizing Tool





Cooling Tank

Extrusion Line in Production



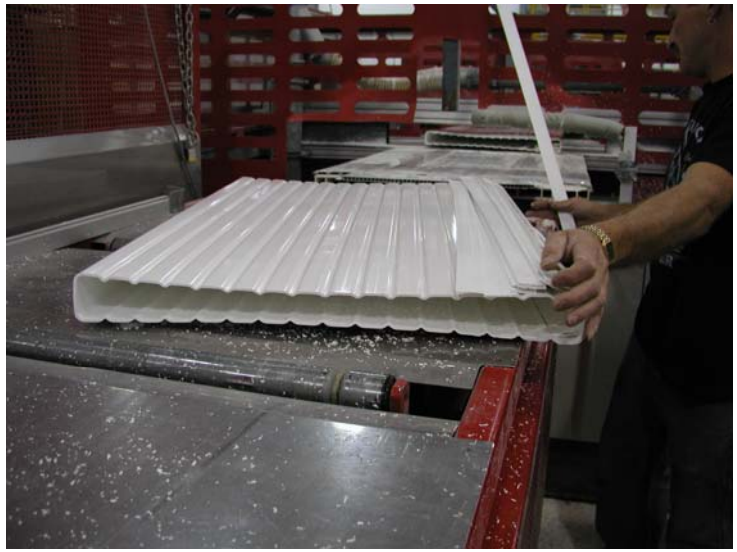
top of extruder

extruding direction

exiting cooling tank

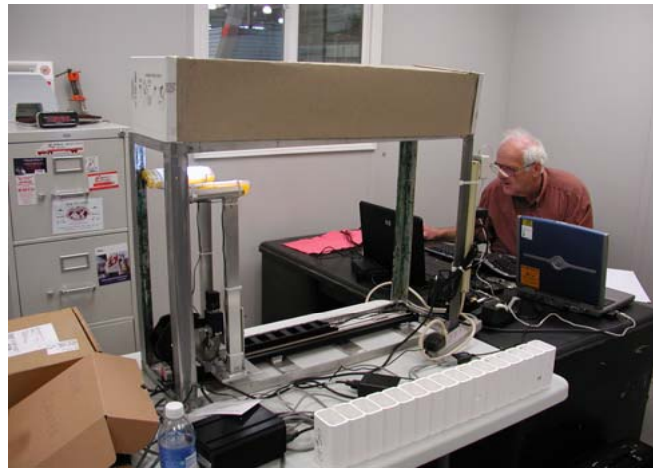
entering the puller

Many Lessons Have Been Learned to Avoid this Outcome



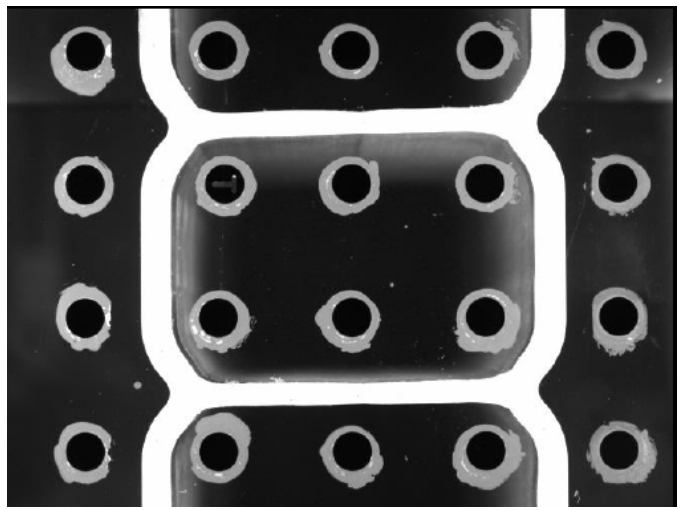
QA and Evaluation on Site

Hydraulic pressure test machine



Photographic measurement

Vacuum test



Profile and fiducial marks

Long Term Creep Tests at ANL

52-foot Extrusions at Extrutech

For the Full Size Assembly Prototype (FSAP) at Argonne

FSAP Layer 1 in Building 366 (2009)

Extrusions for Layer 2 (of 5)

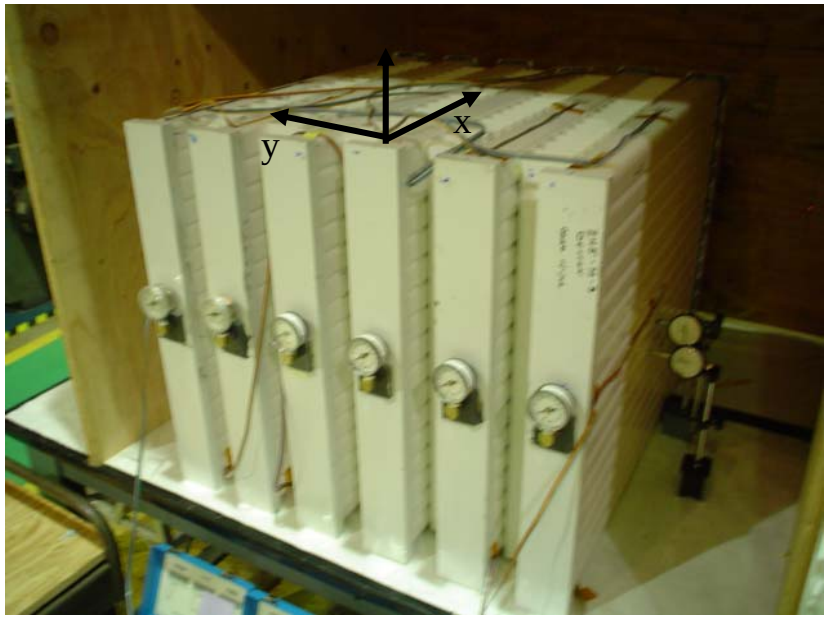
Assembly

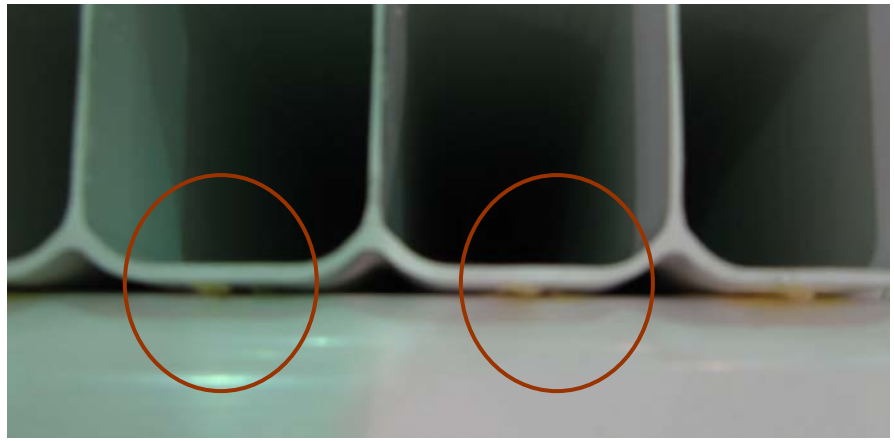
All NOvA Detector Assembly Prototyping takes place at ANL

Here are some highlights

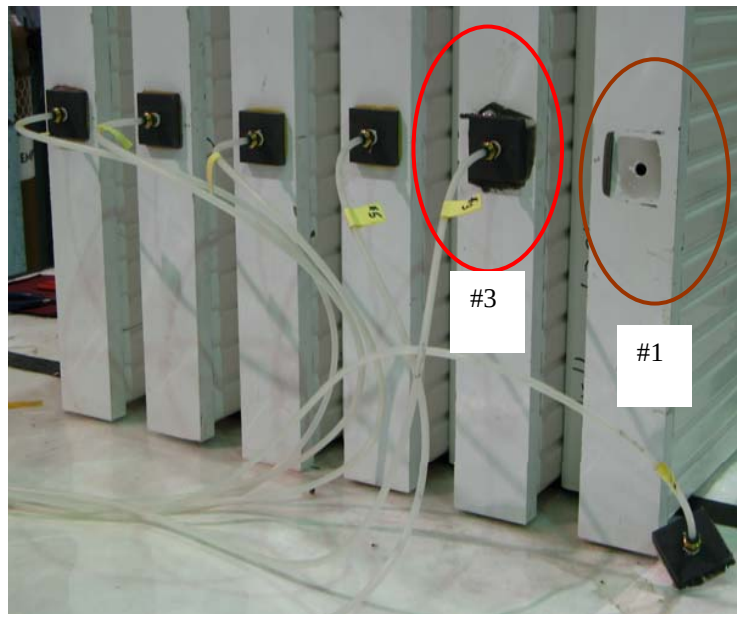
- 11 Plane pressure test
- Load Stability Test (2007)
  - Verified that water-filled extrusions can support the weight
- Assembly Machinery (2008-2009)
  - Vacuum Lifter
  - Glue Machine
    - Safety of Devcon Adhesive has been demonstrated with several thorough reviews
      - MMA vapor: fire/explosive danger and personnel hazard
  - Rotation Device
- Documentation and numerous Safety Reviews led to construction of…
- **Full Scale Assembly Prototype (FSAP) (2009)**
    - **Proved that Assembly Machines work**
      - **Identified areas for improvement**
    - **Validated Time and Motion Estimates**

11 Layer Pressure Test



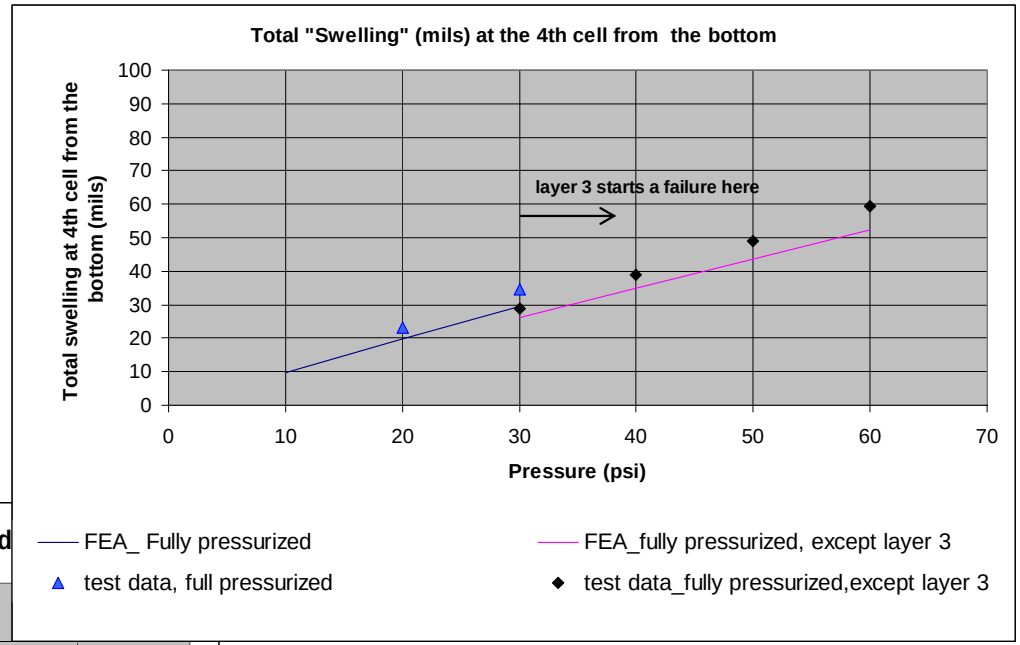


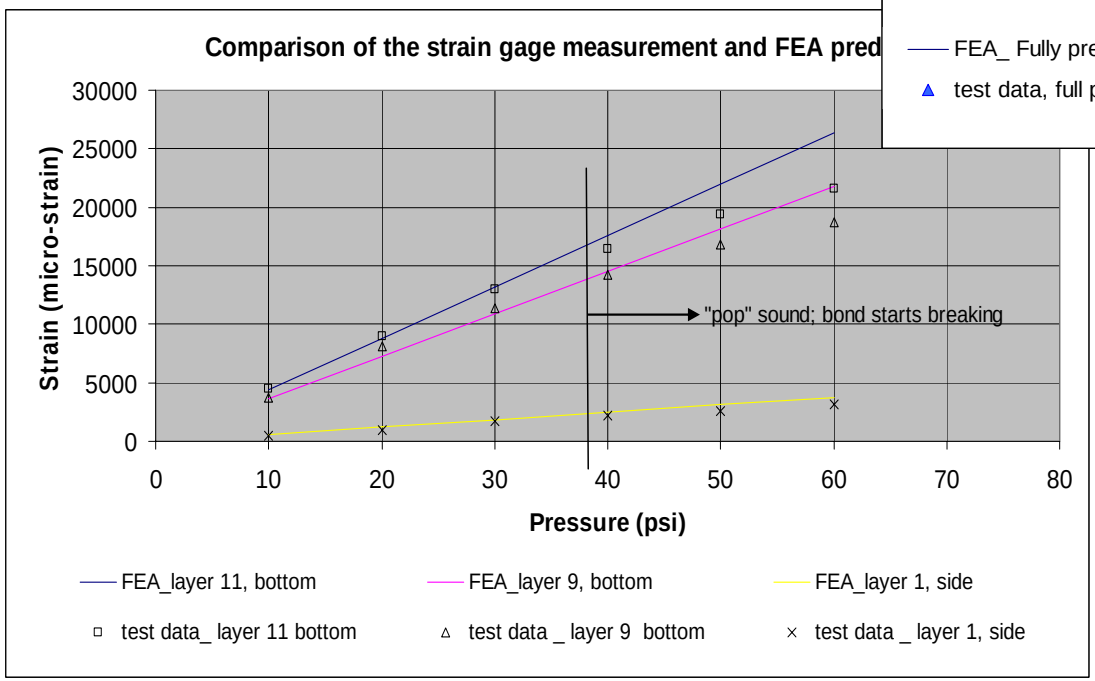
- Increase 10psi of pressure and hold for 1 hour; increase pressure to failure
- Popping noises were heard at 36psi, More for 10 minutes at 40psi to 60psi
- Peeling failure of the adhesive bonds
- Failures occur either at bond or PVC



11 Layer Test –Displacement & Strain

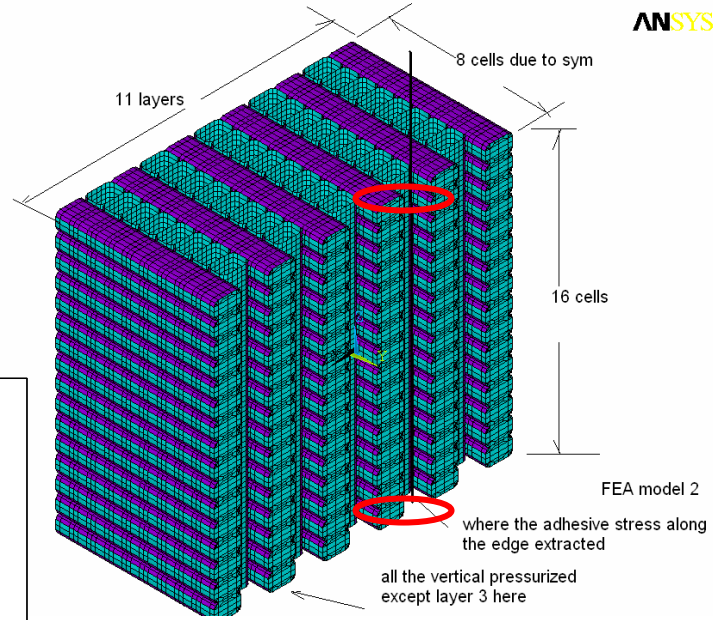
- FEA agrees experiment data for both displacement and strains reasonable well

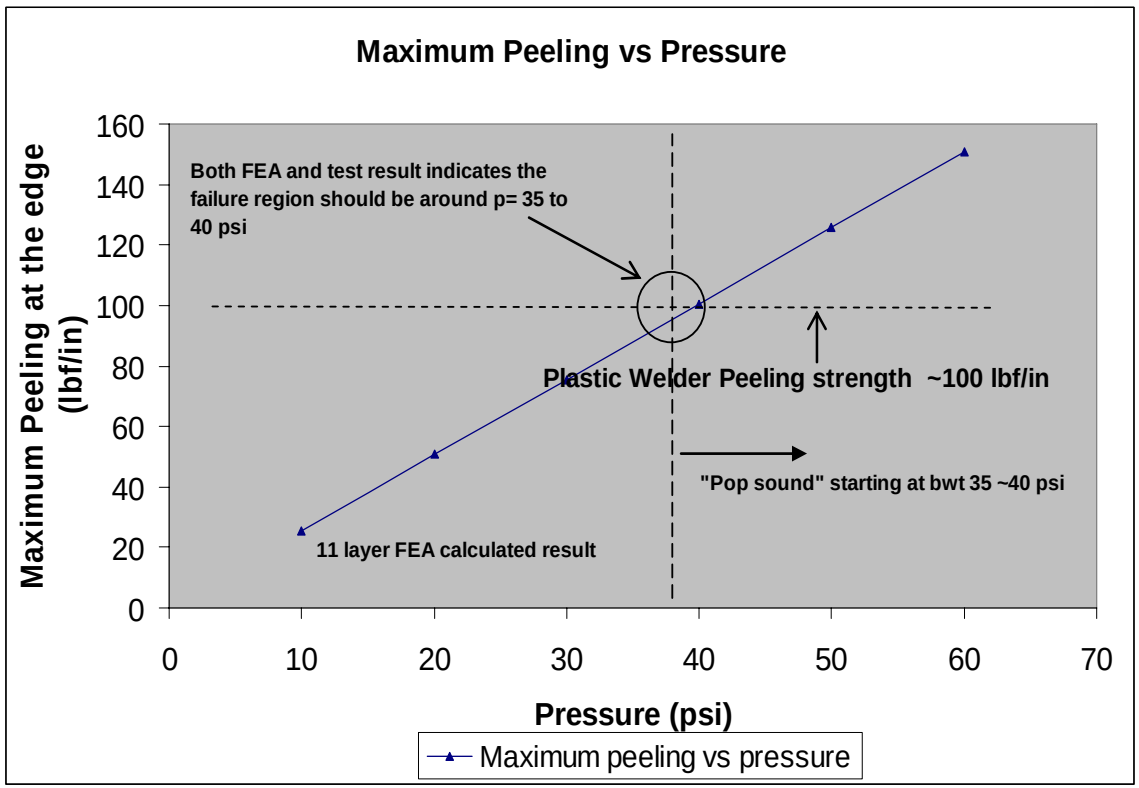


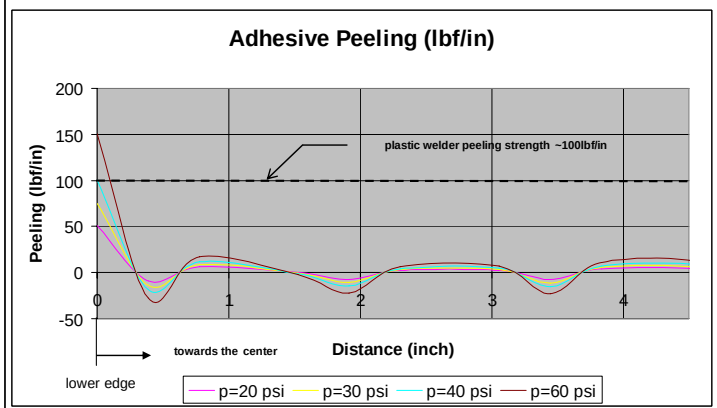


11 Layer Test – Adhesive Peeling

- Adhesive Peeling Strength – 100 lbf/in
- Pop Sound starting at 36 psi
- Bond failures do NOT propagate







First IPND Mechanical Prototype

Vertical Load Test using first IPND Prototype

- First structural test of large prototype
- 4 vertical and 4 horizontal planes
- Each vertical plane had 4 extrusions, each horizontal plane had 6 extrusions.
- Each plane was glued together using **Devcon 60.**
- The vertical extrusions are "**thin-wall**", same the horizontal extrusions.
- Block base grouted like far detector to fill gaps under vertical extrusions

Experiment Setup – Grout

- Required to stand on the floor independently without any support.
- The IPND prototype is grouted on the floor

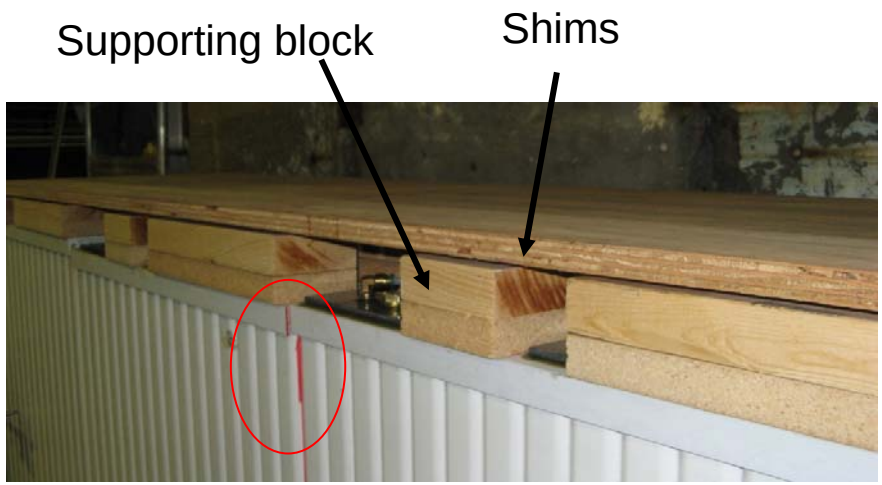
Experiment Setup – Shield Blocks

- A shield made by big concrete blocks for protection in the event of catastrophic failure of the extrusion/end-seal while being pressurized and loading
- Three sides are enclosed by the concrete blocks. Two side blocks, consisting of one B and C blocks, sit at sides of the IPND prototype. A front block consisting of eight B blocks stand in the front of the IPND prototype. On top of theses blocks, a C block is placed and banded to the base front blocks.

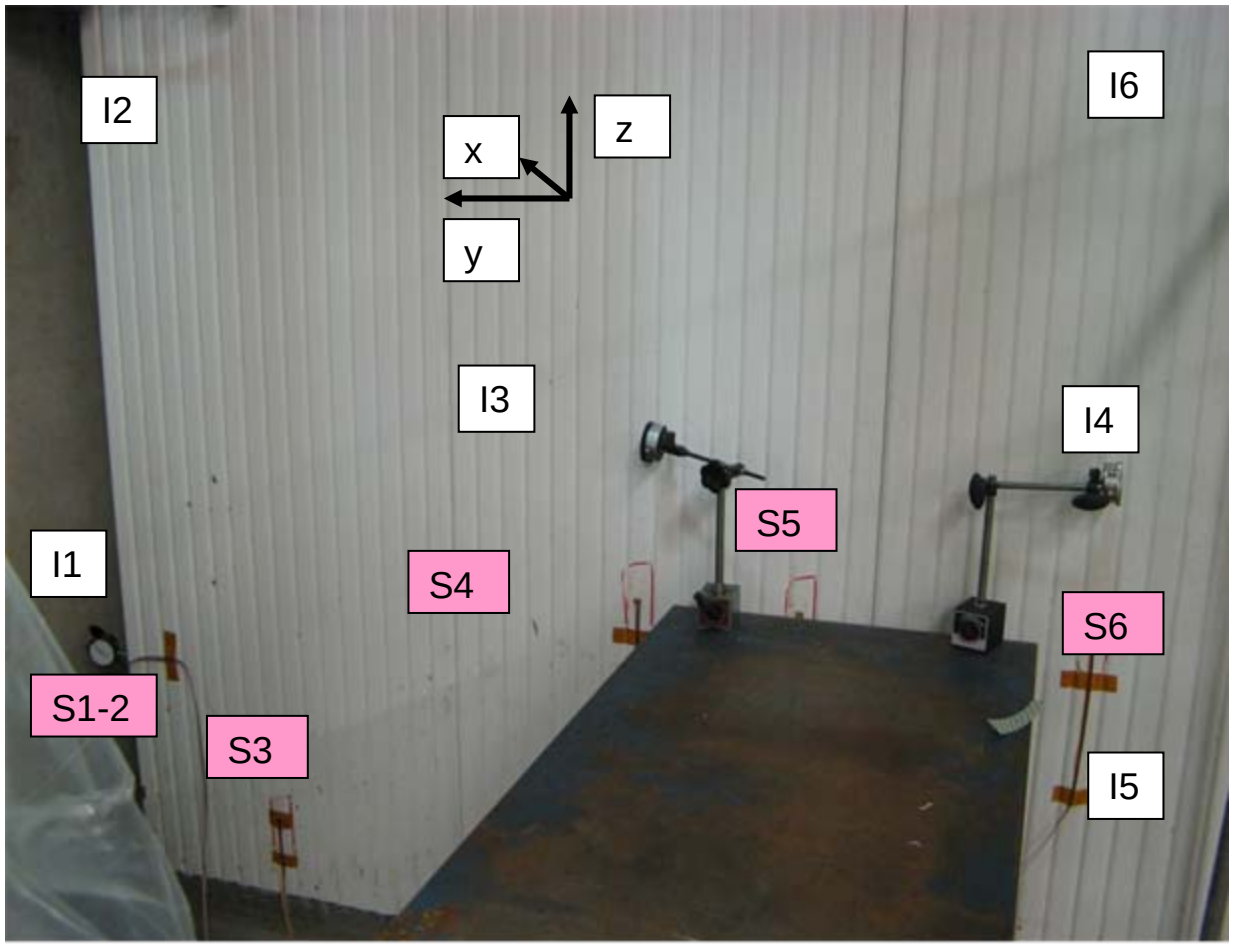
Experiment Setup – Shims

- Two support blocks with the height of 5 inches sit closely to the patch. A big 0.5 inch shim block on the top.

- Both the support blocks and shim blocks are leveled to facilitate even loading on the vertical extrusion from the weight blocks. This ensures the weights blocks seat steadily and there is only vertical loads with no moment applied to the IPND prototype.

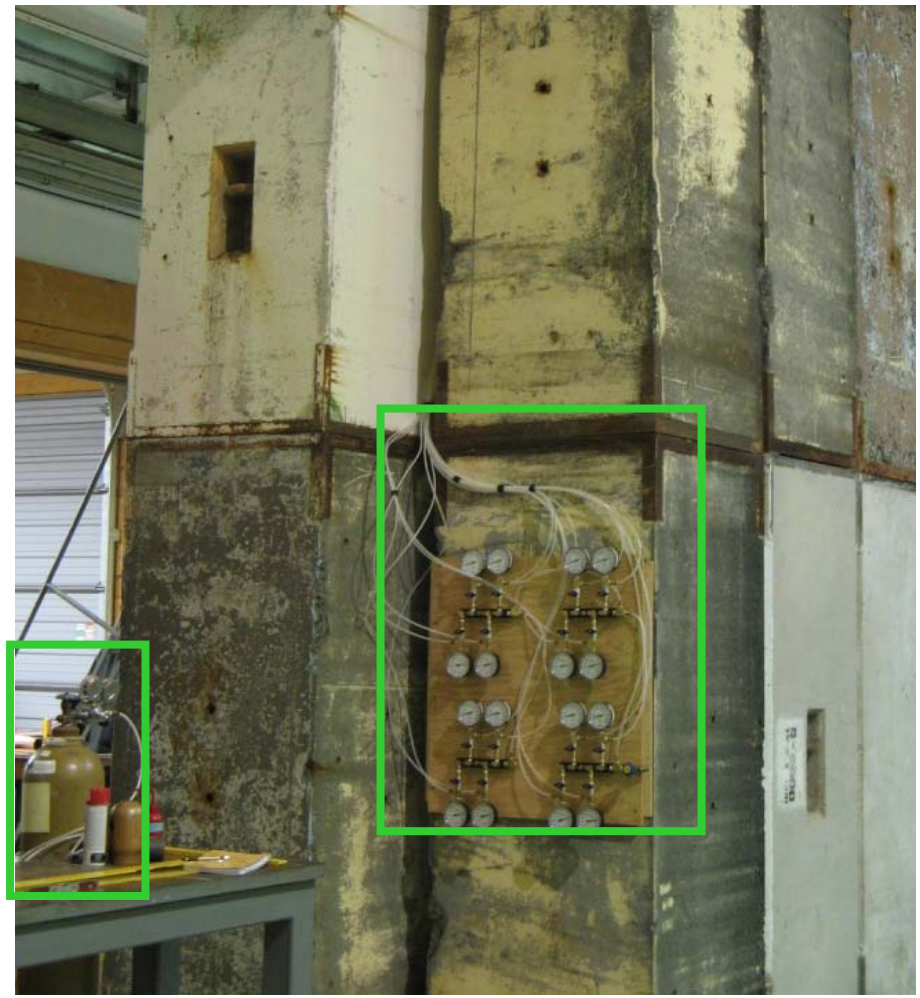


Instrumentation



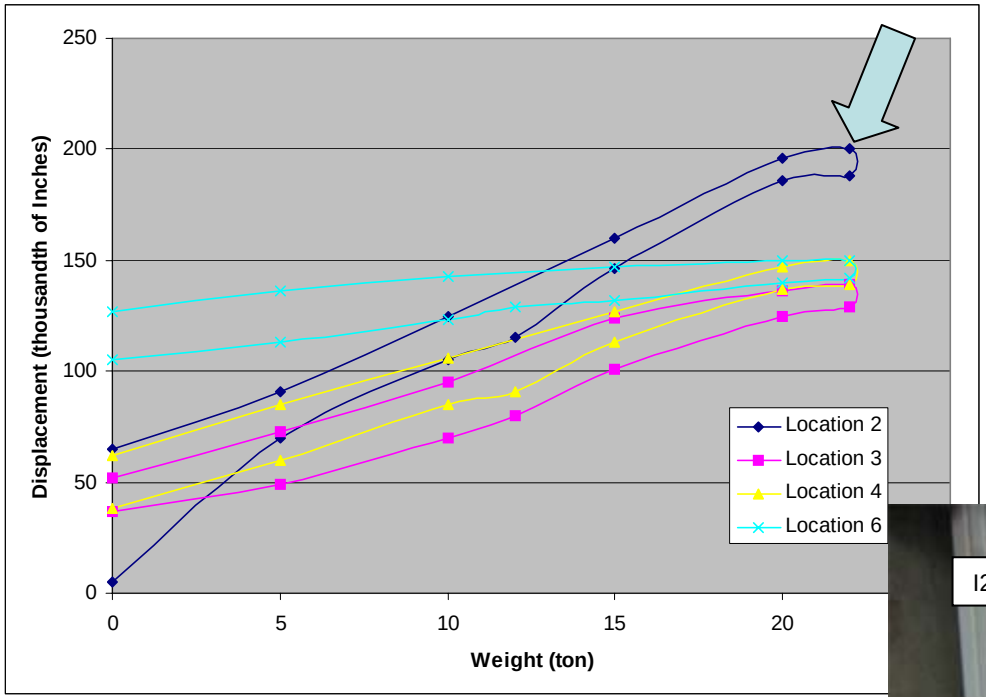
Apply Pressure

- Vertical extrusions are filled with water.
- An additional 14psi of air pressure is applied at the same time for all the extrusions to achieve 19psi at the bottom.



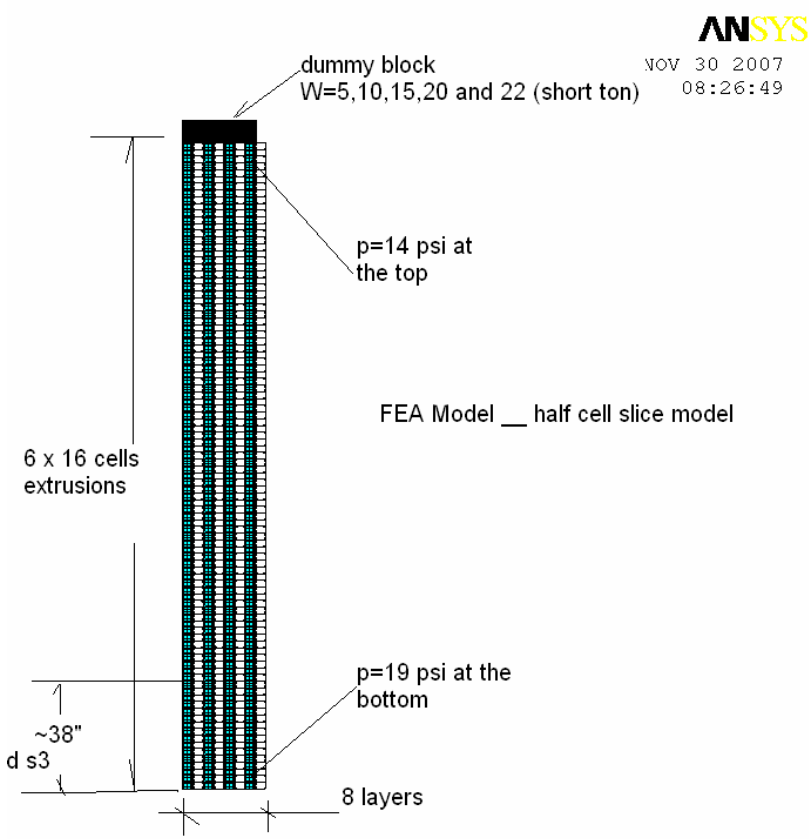
Loading Weight

Displacement

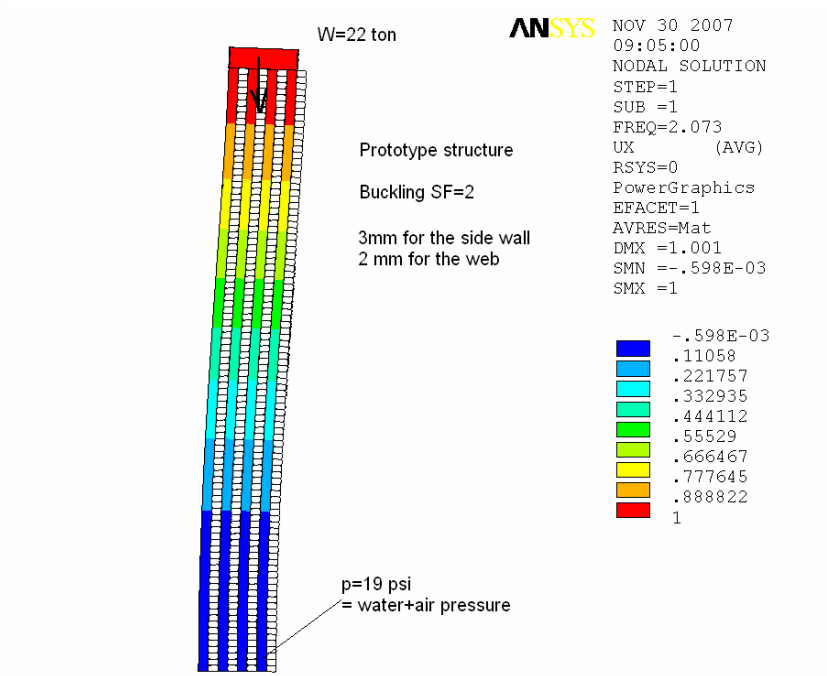


- 91 thousandth of inch by FEM
- Creep

FEM Comparison - Buckling

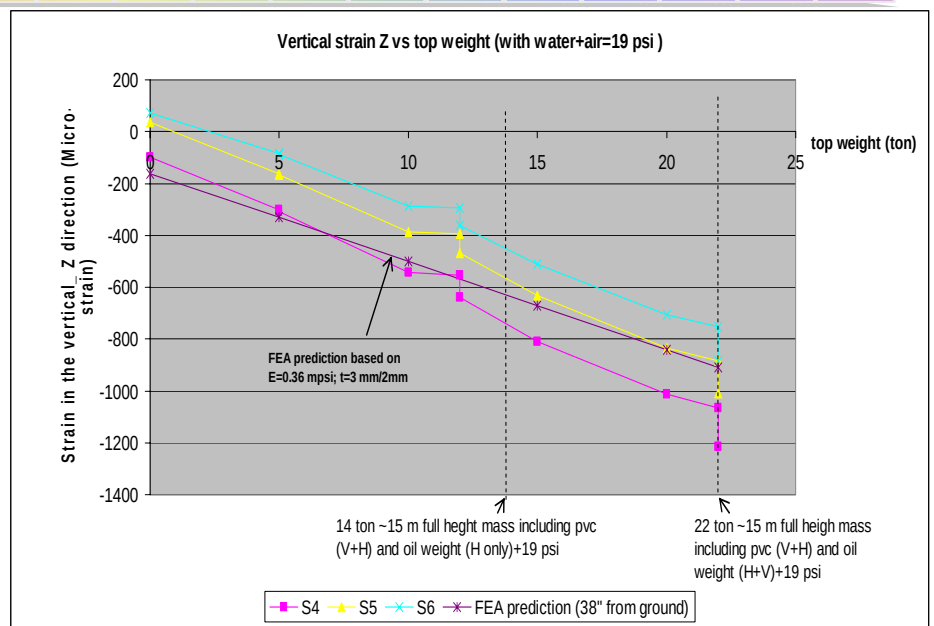


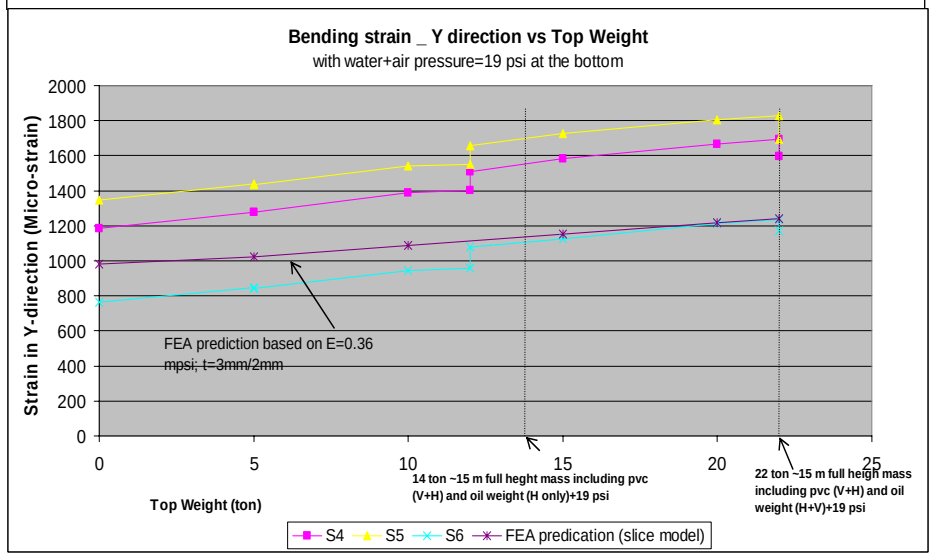
- half cell slice model
- Predict it is safe at 22 tons



FEM Comparison – Strain

- FEM strain predicated bounded by experiment data
- Hand calculation shows 738 ustrain in Z-direction





Load Test Conclusions

- The IPND prototype was successfully loaded with internal pressure and weight. Achieved load safety factor of 2 without any failure.
- FEA analysis agrees with the experiment results reasonably well.
- Creep is observed when load is applied for some time.

The Eight-Plane IPND Prototype Test

Allen H. Zhao, Victor Guarino, David Ayres,
Ken Wood, Tim Nephew – ANL
Ang Lee – FNAL

New Assembly Tasks 2009-10

- **IP/ND** (Integration Prototype/ Near Detector)
  - 4.3 m high x 2.9 m wide
  - 6 blocks
    - 31 x-y planes per block
  - Shipped to Fermilab, installed on surface (IPND) (2010)
    - Filled with liquid scintillator and instrumented
  - Drained & moved in NuMI tunnel (ND)
- Requires a different vacuum lifter & transport
  - Fixture attached to forklift with rotation capability
- Assembly begins in October 2009
  - Engineering prototype of full IP/ND block
- IP/ND block assembly completion expected in Spring 2010

New Assembly Tasks 2010

- **FHEP** ("Full Height" Engineering Prototype)
  - 48.5 m high x 2.9 m wide (height restriction)
    - PVC mass is 23 Tons, to be filled with water
  - 1 block, assembled on prototype block pivoter
    - Block pivoter is being made at Fermilab and will be transported to ANL
- This is the final large-scale prototype assembly before installation at the FD site (Ash River).
- Assembly begins when prototype block pivoter is completed and tested at Fermilab: February 2010.
- FHEP will be shipped to Fermilab, pivoted to a vertical orientation, instrumented with strain and deflection gauges and filled with water. Deflections will be compared to FEA calculations.

Summary

- Successful R&D production effort with N-27
  - Extrusions for FSAP, IPND and FHEP have been produced with good results
- Extrusion QC methods are nearly finalized
- Assembly work continues at Argonne
  - Glue machine, rotation device & vacuum lifter working well
  - FSAP completed
  - IP/ND assembly to commence in October 2009
  - FHEP assembly will begin this winter
- Assembly Equipment will be packed and shipped to Ash River toward the end of FY2010.