Construction of PVC Extrusions for NOνA Near and Far Detectors

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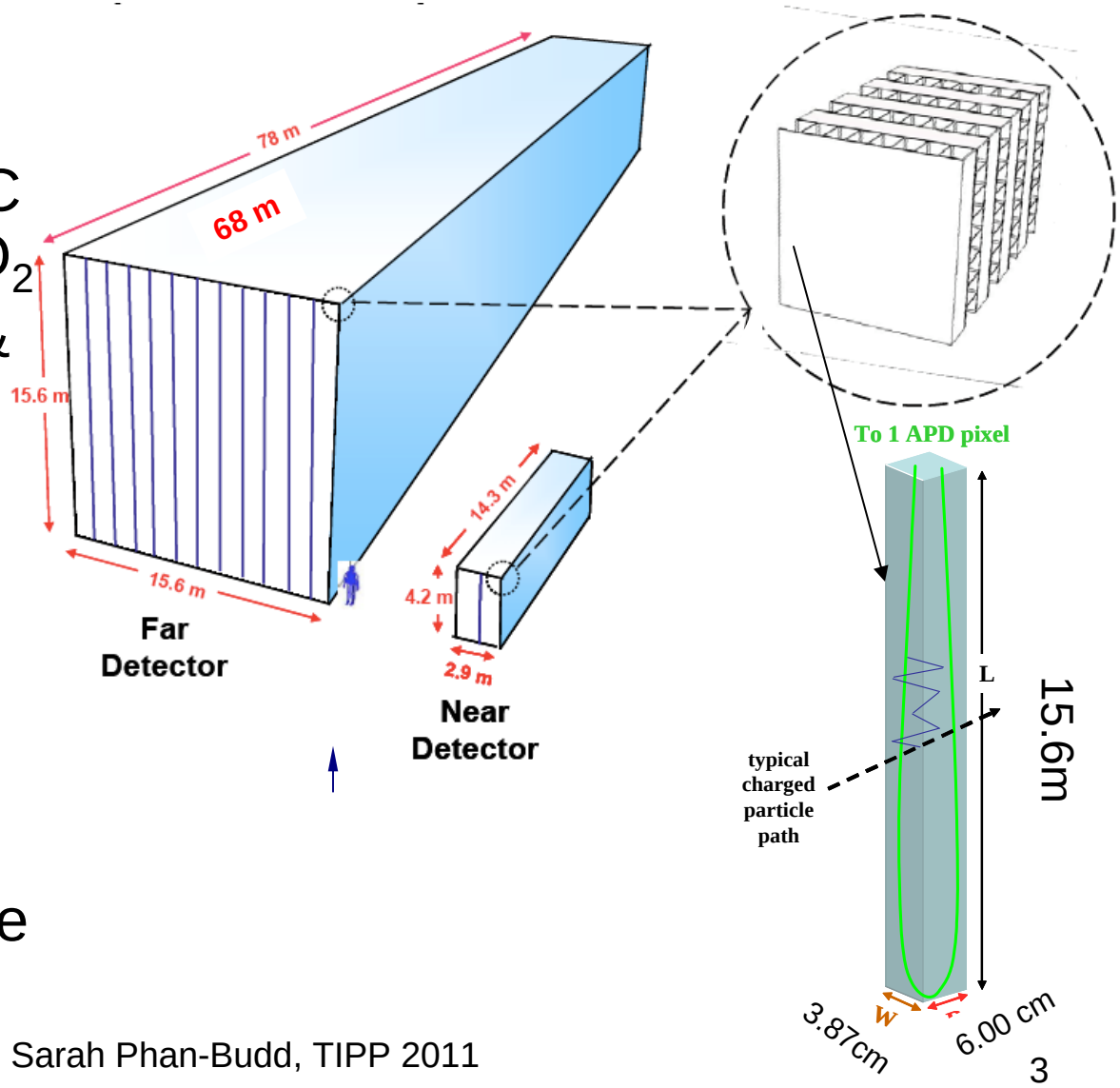
On Behalf of the NOνA Collaboration

The NOνA Experiment

- NuMI Off-Axis ν_e Appearance Experiment
- 14kT Far Detector, 14mr off-axis, in Ash River MN
  - L=810 km E~=2GeV
- 220T Near Detector, at FNAL
- Run for 6 years
  - 3 years each of normal and reverse horn current running
- Goals
  - Measurement of θ_{13}
  - Determination of mass hierarchy via MSW effect
  - Begin to localize δ_{CP}
  - Precise Measurement of $\sin^2(2\theta_{23})$

The NOνA Detectors

- FD: 65% Active Volume, 928 planes
- Planes consist of PVC extrusions w/15% TiO_2
  - Alternate vertical & horizontal orientation
- Liquid Scintillator
- PVC cell for primary containment
- Wavelength shifting fiber
- Avalanche Photodiode
- Low noise amplifier

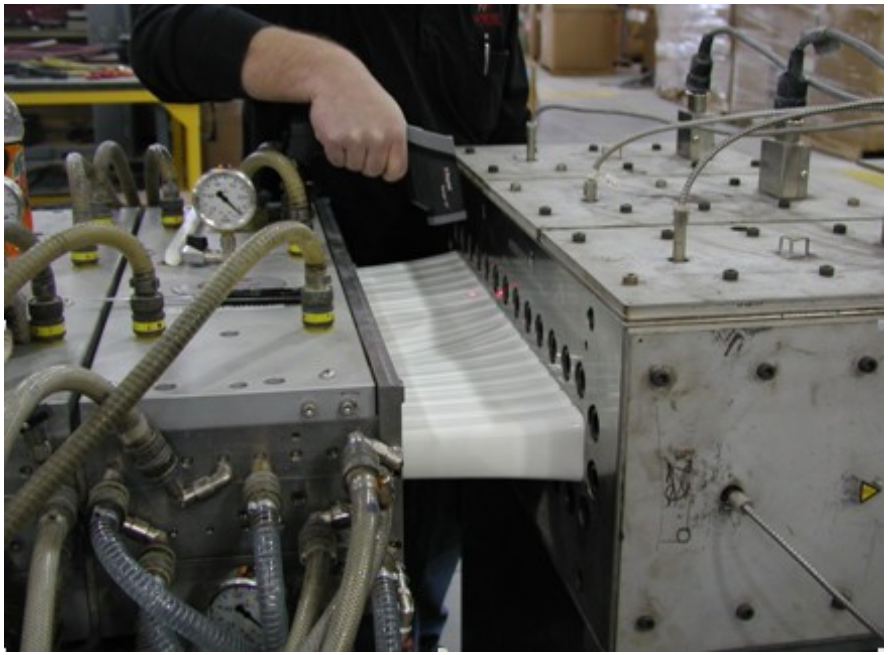


Near Detector on the Surface (NDOS)

- Full test of construction techniques to create a working prototype near detector
  - PVC Extrusions
  - Module construction
  - Block construction
  - Electronics and Outfitting
  - DAQ and NOvA software
- Finished Winter/Spring 2010-2011
- At the intersection of the FNAL NuMI and Booster beams
- Run Goals:
  - Exercise calibration scheme
  - Benchmark MC
  - Demonstrate electron neutrino selection, and cosmic and other background suppression
  - Physics results

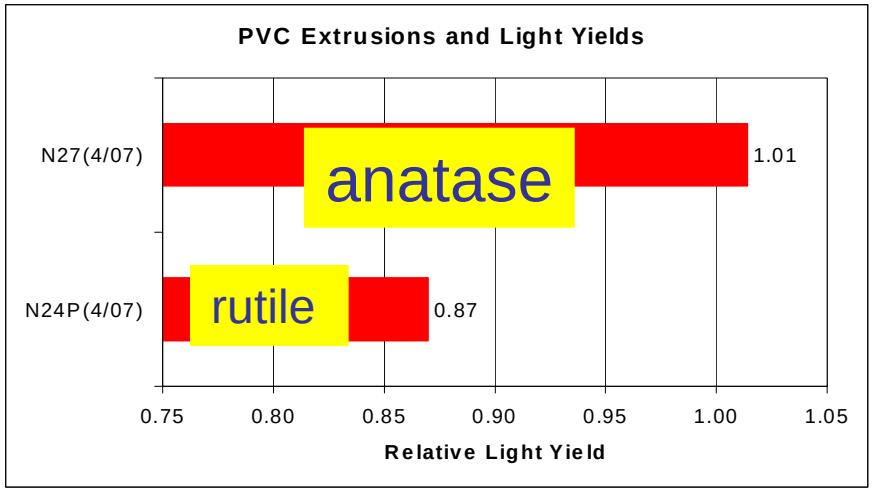
Creating PVC Extrusions for the NOvA Detectors

- Creating physics quality extrusions for the NOvA detectors has presented a number of challenges
- This talk covers:
  - PVC Resin and Powder
  - Extruding
  - Quality Control

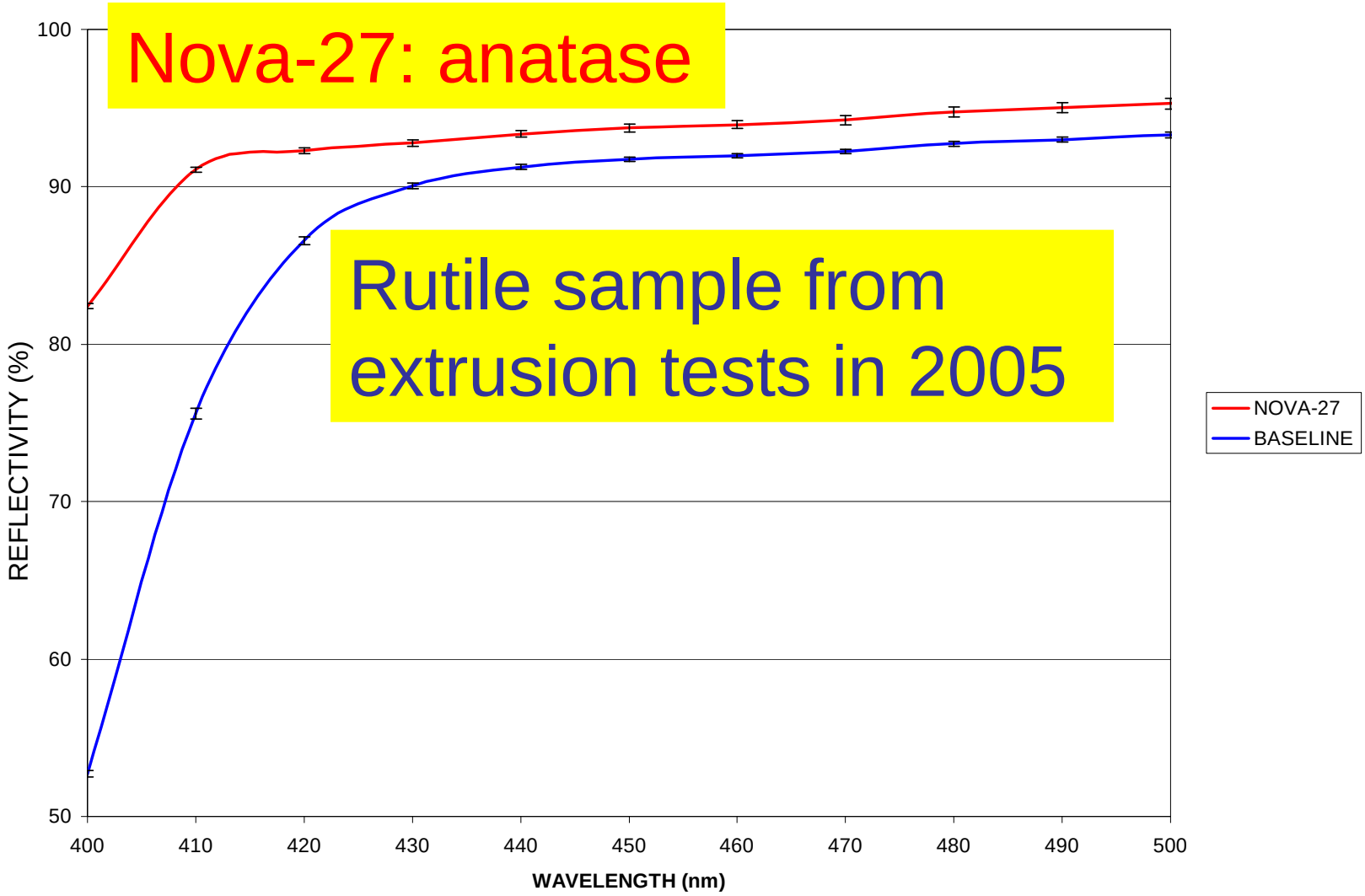


PVC Resin and Powder

- Created a custom PVC Resin for NOvA
  - NOvA27
- Designed with physics needs in mind
  - higher light yield: Use Anatase rather than Rutile TIO_2
  - Maintain good tensile properties

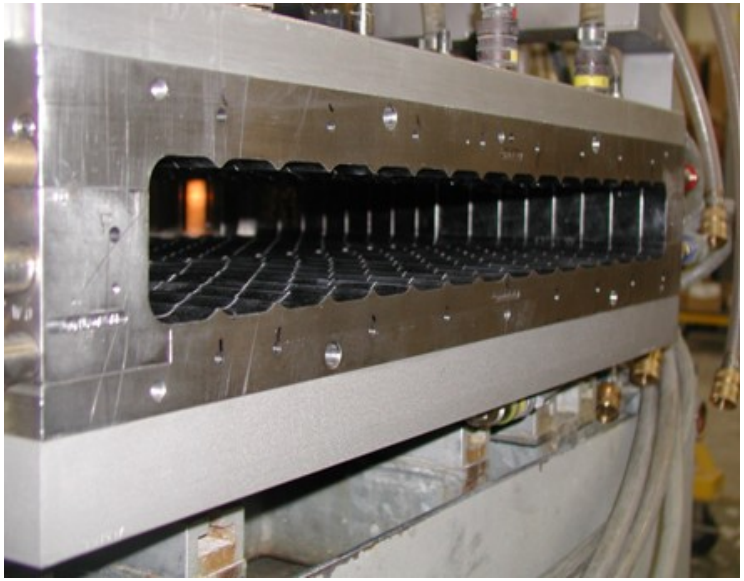


Reflectivity of Anatase compared to Rutile



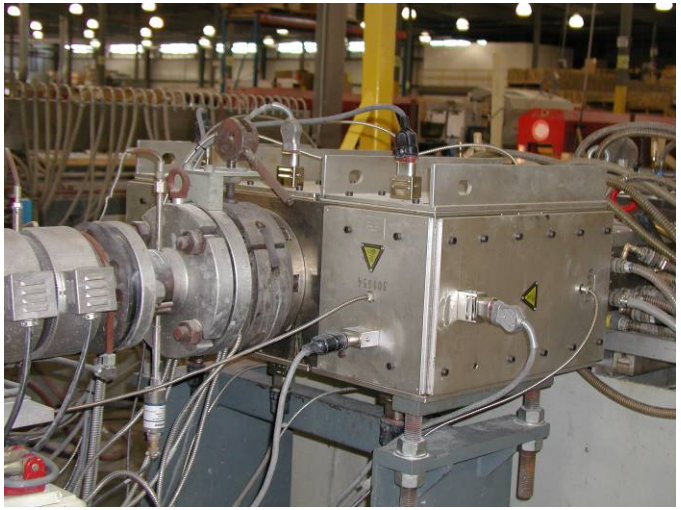
Creating PVC Extrusions

- NOνA extrusions are made using a specially designed die and a designed extrusion line
- A prototype die was used and tested on NDOS extrusions
- This experience was used to create a final die for far detector extrusions

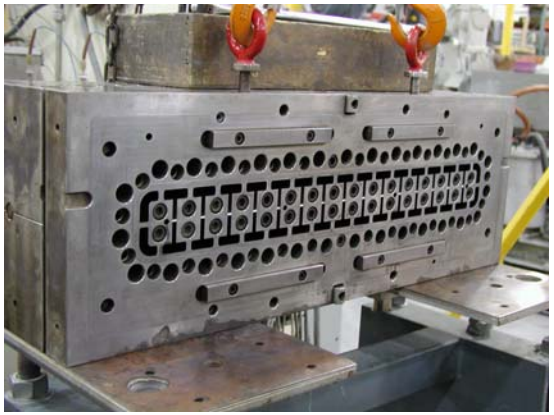


Prototype Extruder and Die

- Extruder
  - **Krauss-Maffei (KMD-60) Twin Screw**
  - 60mm is the diameter each screw
- Extruder PVC output ~ 550 lbs/hour



Assembled Die with Heater Plates



Disassembled Die

Many Lessons Have Been Learned to Avoid this Outcome

Far Detector Extrusions

New KMD-90/32

Twice the throughput

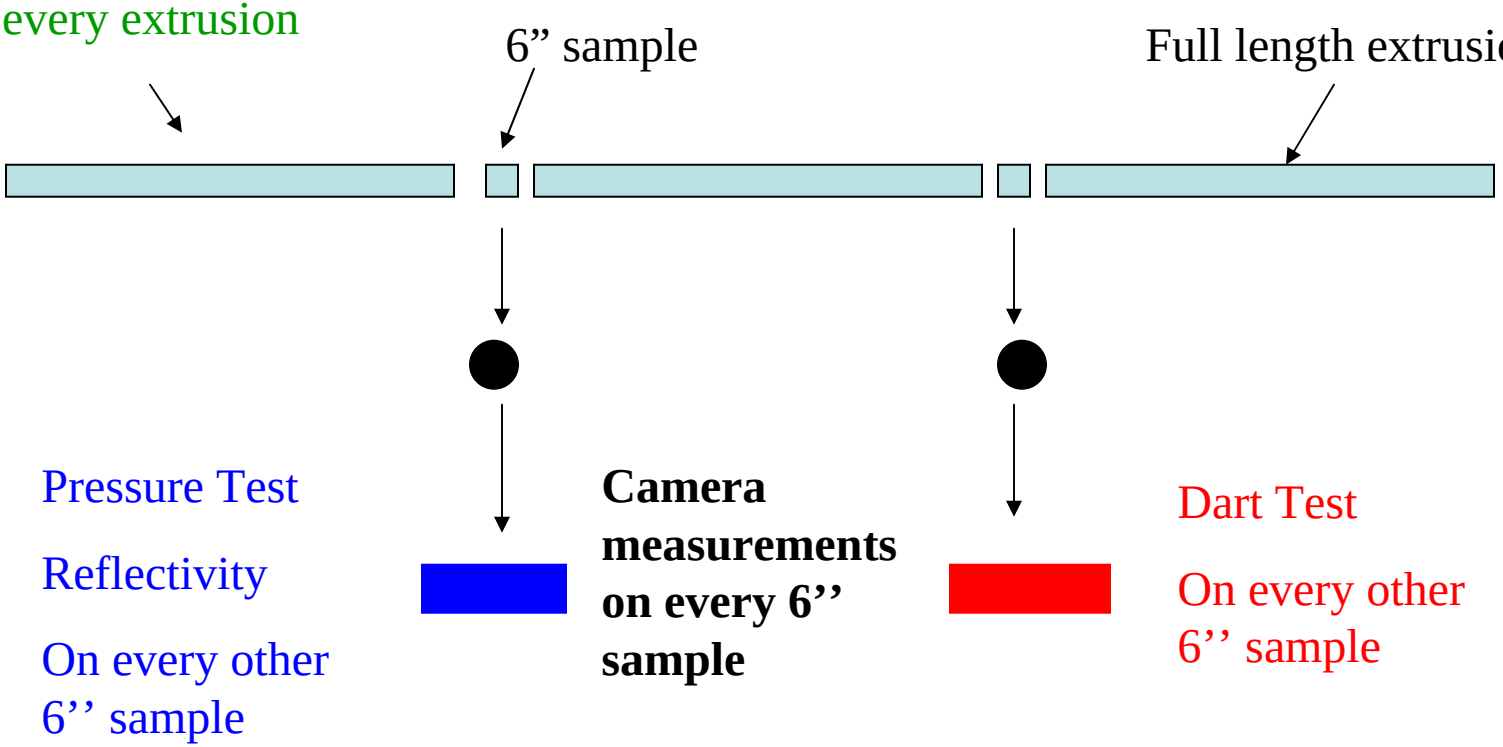
New Dies, Calibrators and Cooling Tanks

Extrusion Quality Control

- A number of quality control tests are performed to ensure physics quality extrusions
- Measured properties
  - Mechanical: drop dart, tensile tests, pressure and vacuum tests, creep
  - Reflectivity
  - Dimensional: camera, flatness measurements, caliper measurements

QC Process

Isolated cell vacuum test
Done on every extrusion

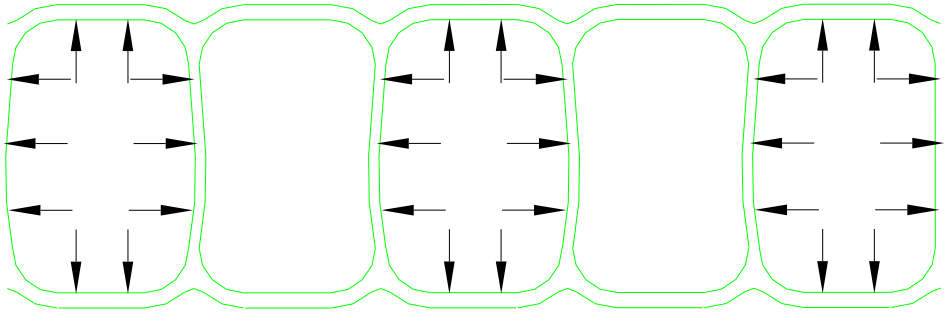


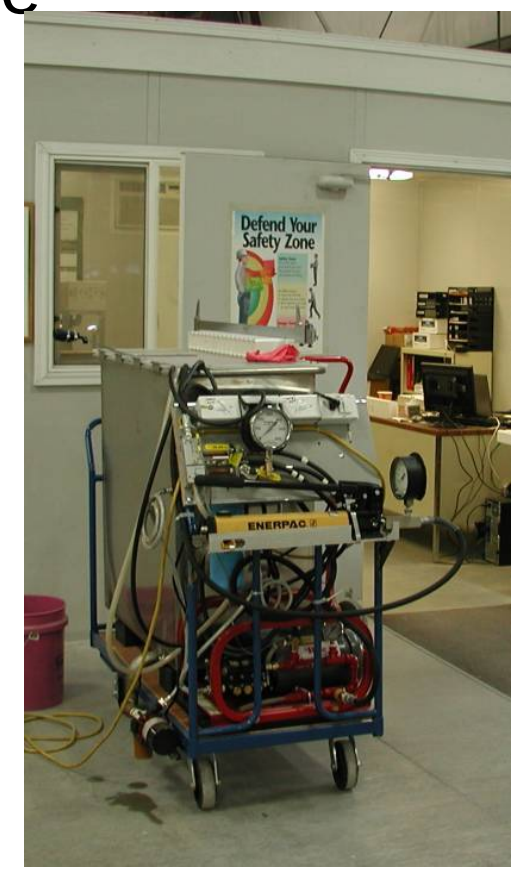
Tensile tests performed weekly from samples taken once per day. Test performed at ANL.

Creep samples created bi-weekly.

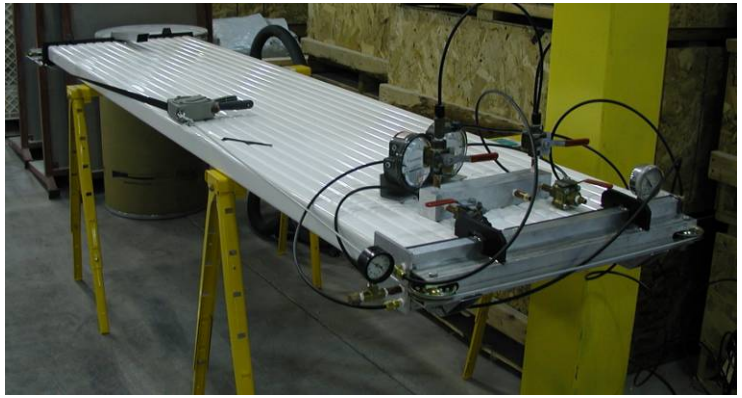
Pressure Tester

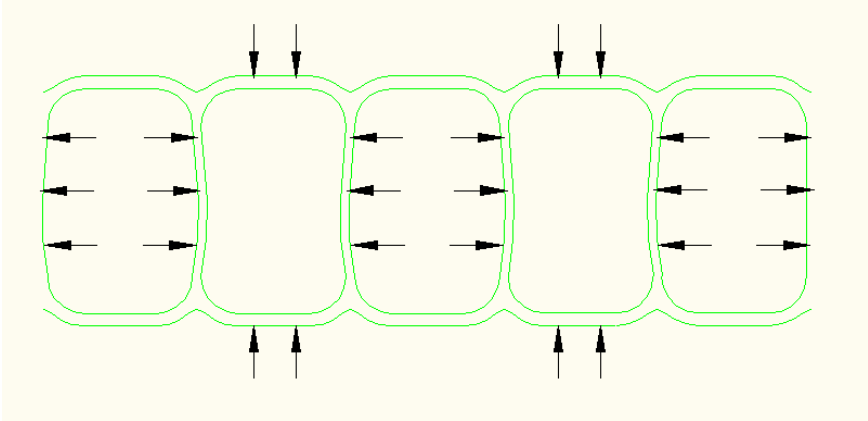
- Pressure tester pressurizes alternate cells.
- This tests internal webs and outer walls



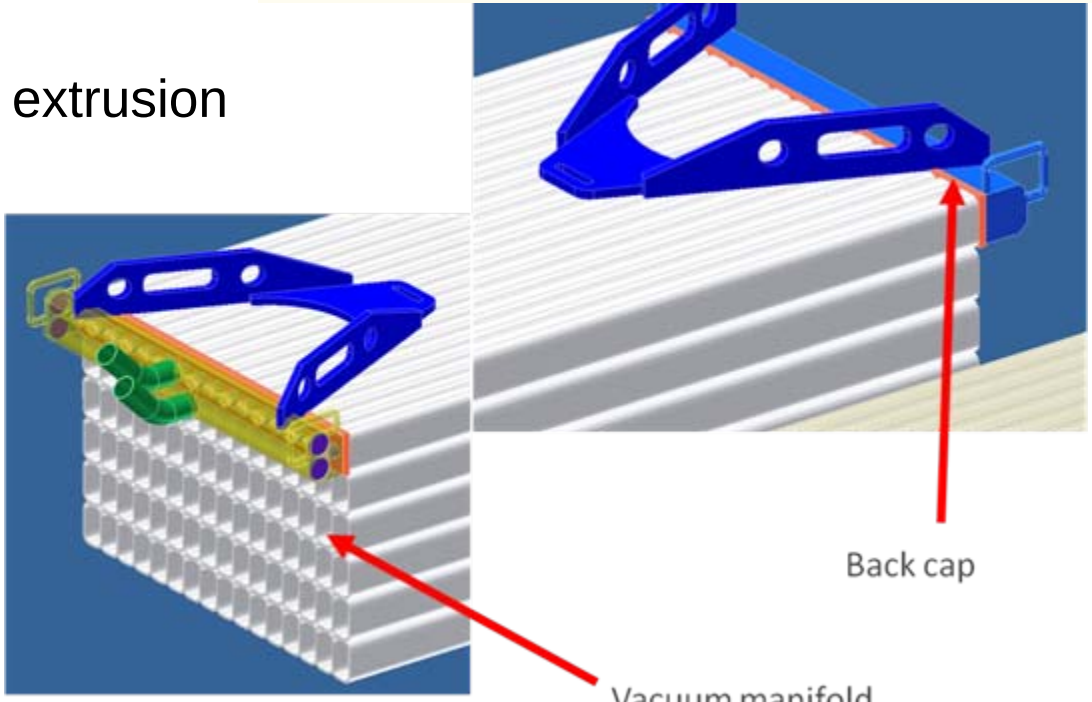


Vacuum Tester

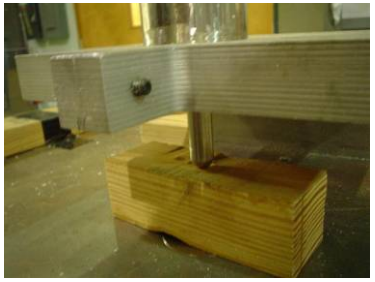




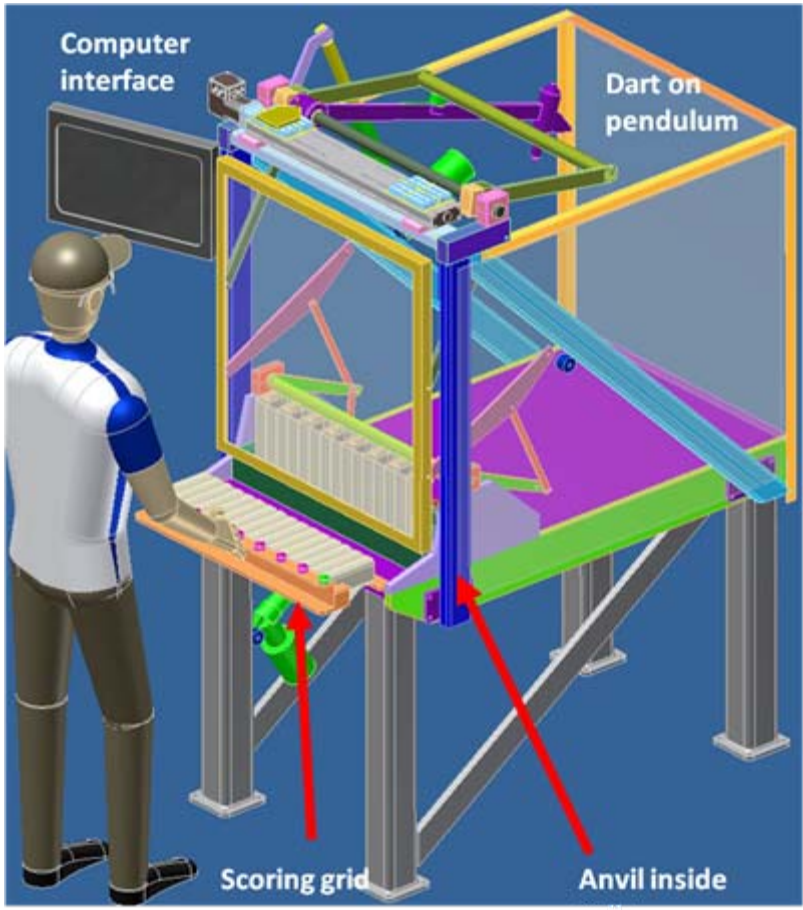
Vacuum test checks for Web knitting/buckling- for entire extrusion



Drop Dart Test



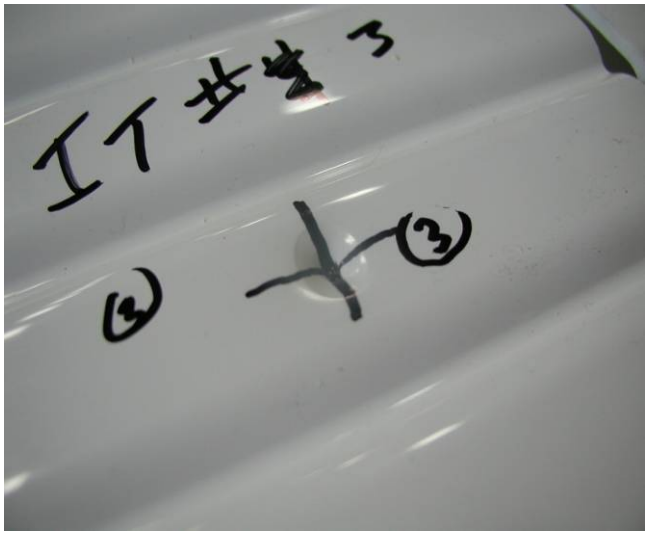
- Prototype version show (left)
- Production version (right)
- Fully automated testing Auto clamping and internal anvil should enhance consistency of results

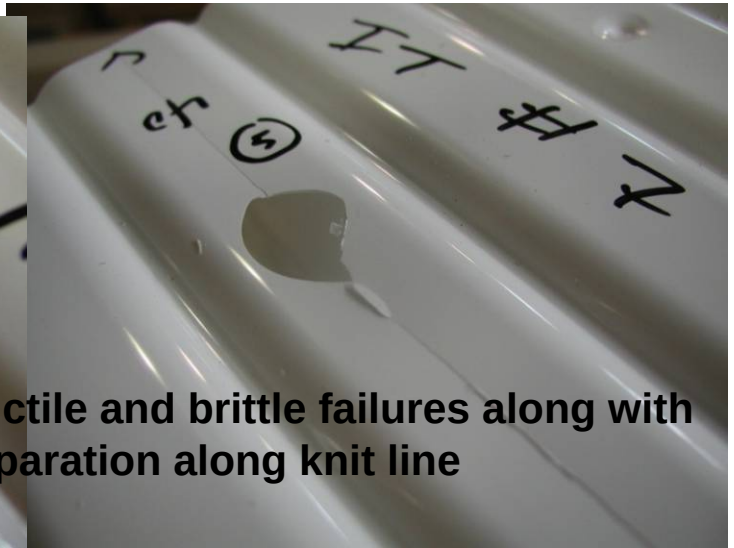


Drop Dart Impact Results

Relatively deep and shallow dimples prior to failure: good and poor ductility

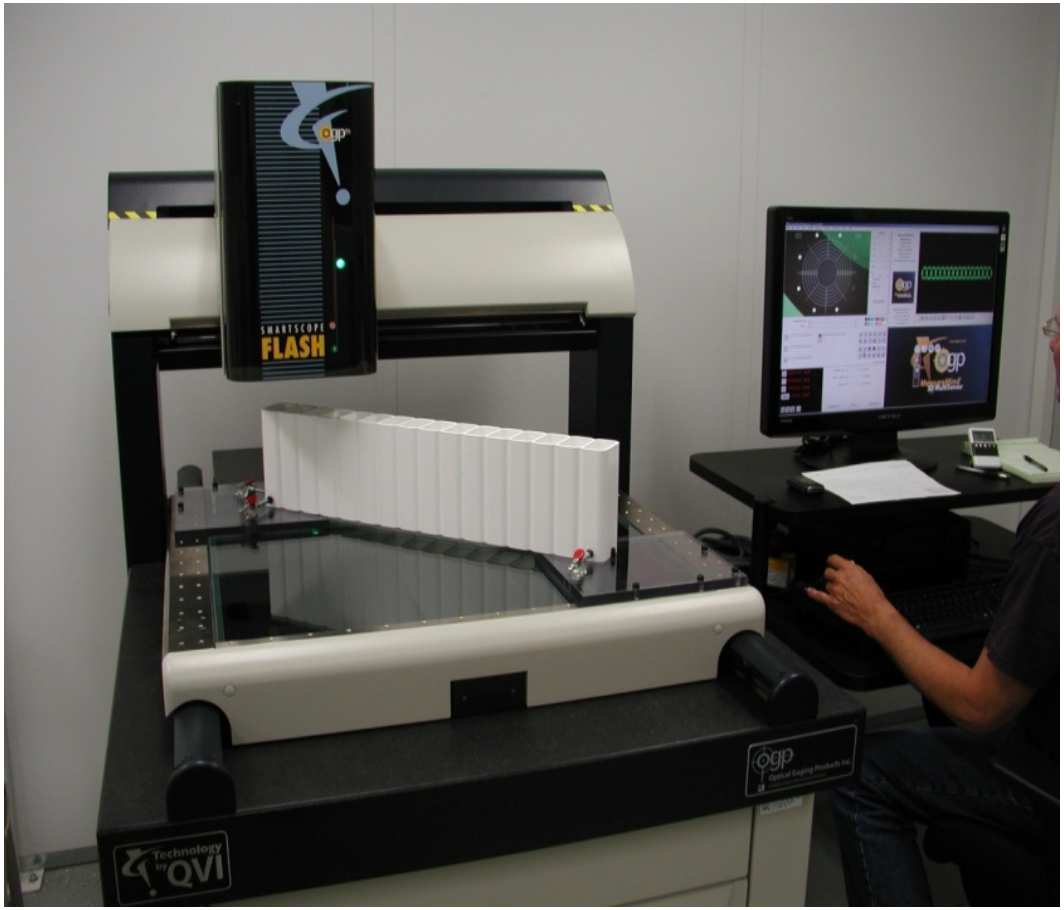
Brittle failure / fracture through “continuous” material





Ductile and brittle failures along with separation along knit line

Camera: Dimensional Measurements

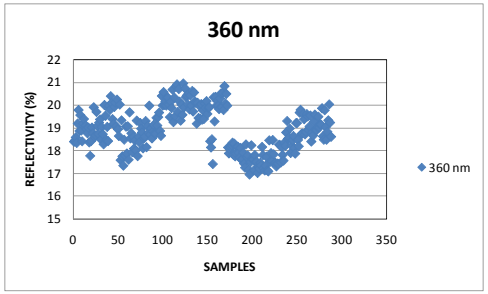


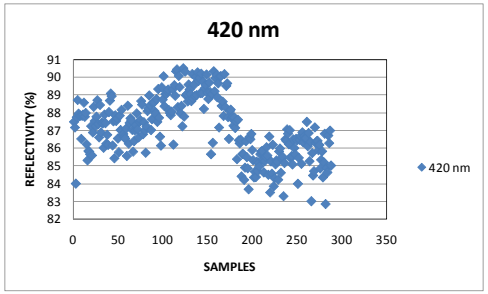
- OGP metrology machine measures:
  - **Flatness (straightness)**
  - **web thickness/ location/ perpendicularity**
  - **wall thickness**
  - **radii**
  - **Overall and individual cell height**
  - **Width**

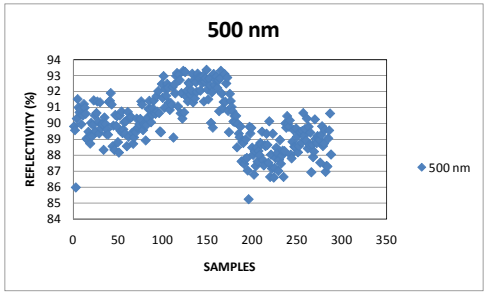
Reflectivity

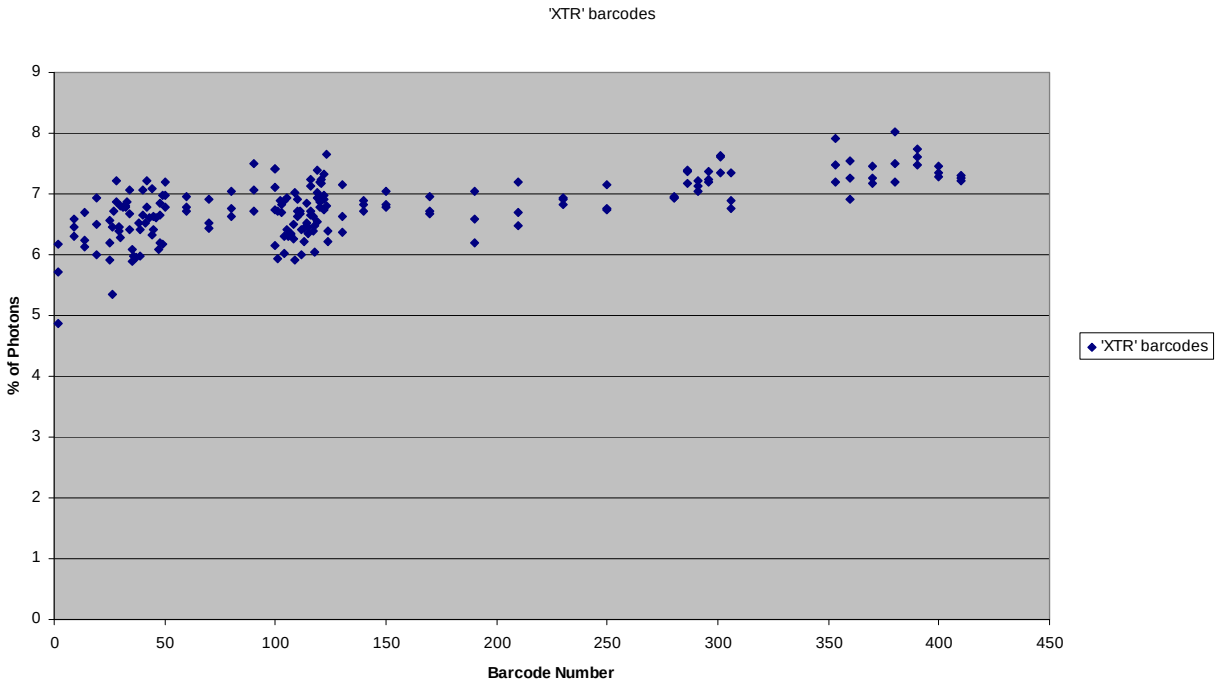
- Table top spectrophotometer
  - “non-specular” mode
  - Extended range to 360 nm
- Cutting fixture allows QC measurements of interior
- All measurements done at the Extruder

Light Yield





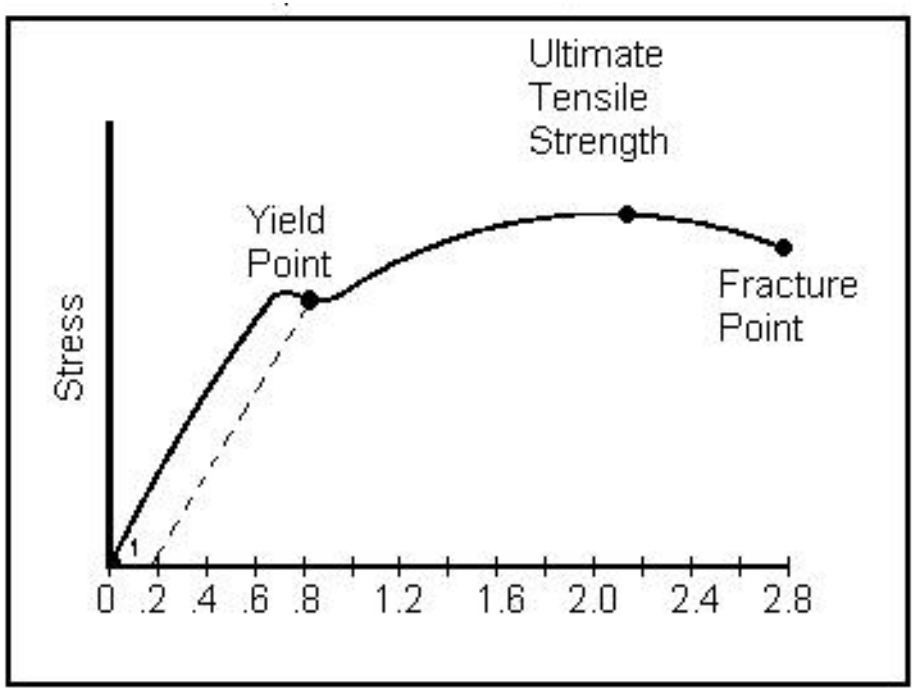




Reflectivity measurements are taken at wavelengths from 340nm to 470nm and these are used to create a relative light yield using MC simulation

Mechanical Properties

- Modulus, Yield, Ultimate stress come from ASTM tensile test-daily at ANL
- Creep samples started every 2 weeks
- Tensile test results can indicate knitting problems

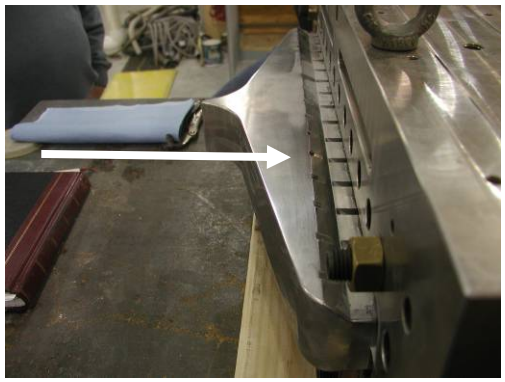


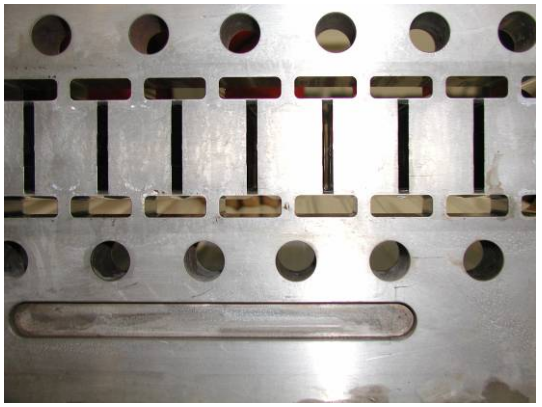
Conclusions

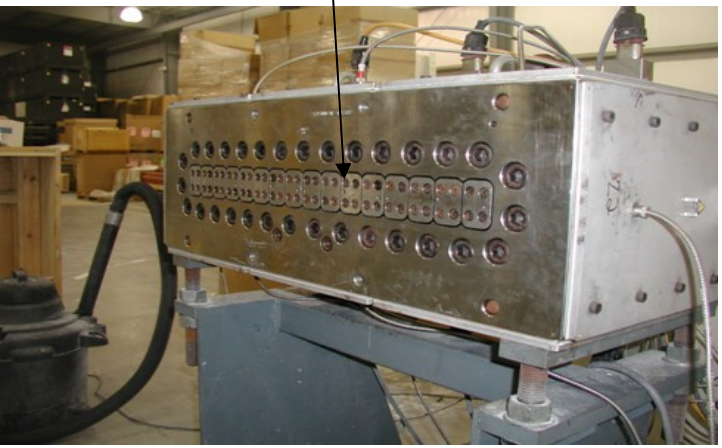
- The NOvA detector is created using a novel technology of extruded PVC tubes filled with liquid scintillator
- In order to create physics quality NOvA extrusions, several new pieces had to be developed
  - New NOvA resin
  - Extruder dies and extruding technique
  - Quality control procedure
- Techniques have been prototyped and tested on the NDOS and extrusions are now being created for the far detector

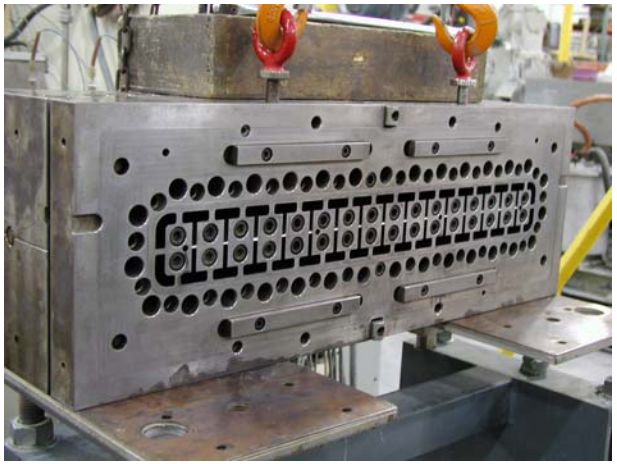
Backup

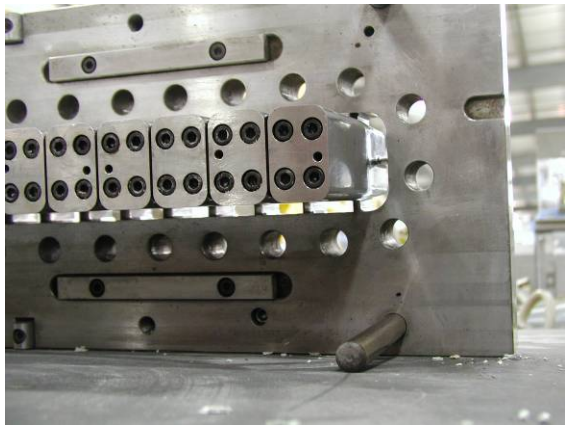
NOvA Prototype Die: Disassembled







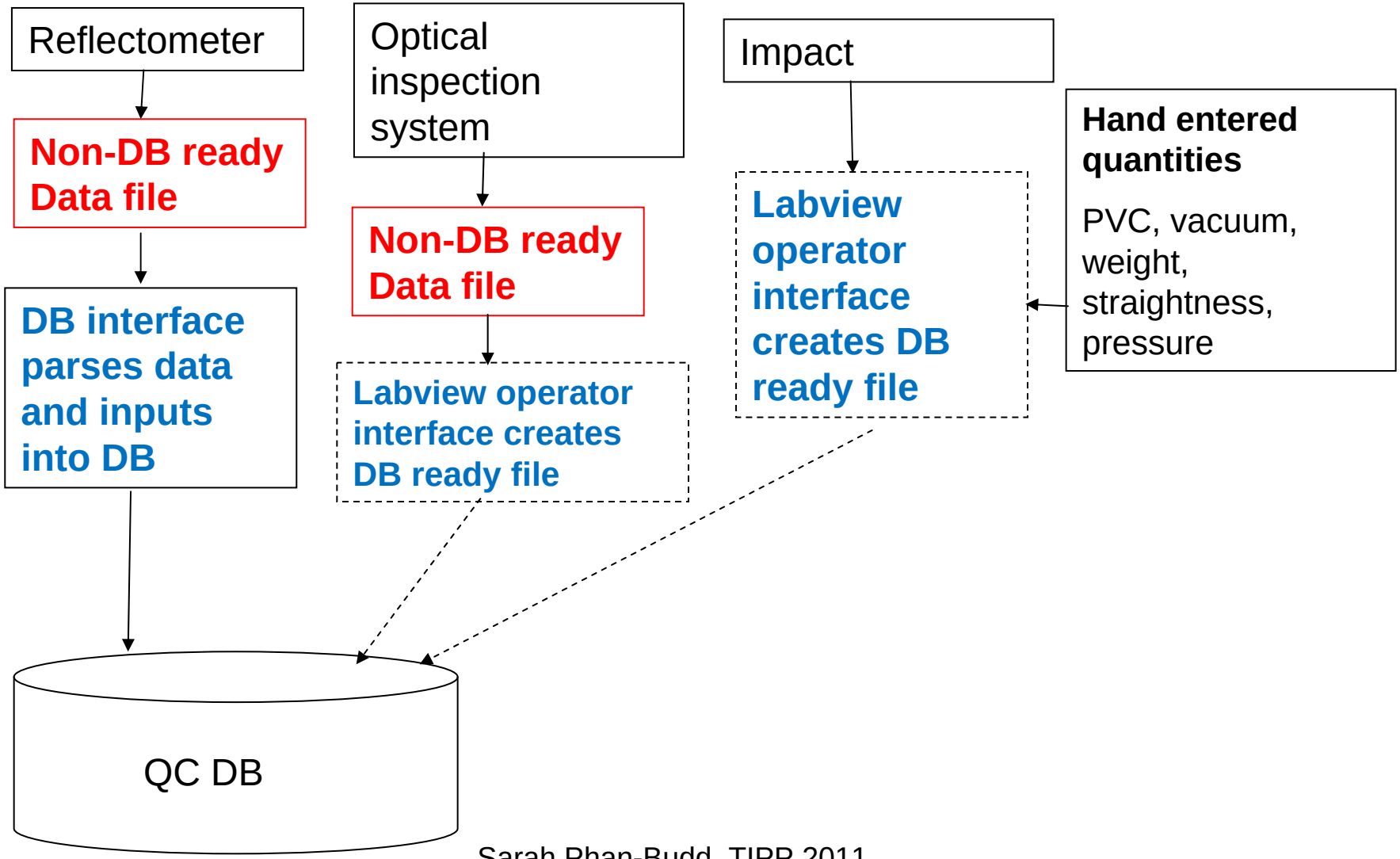




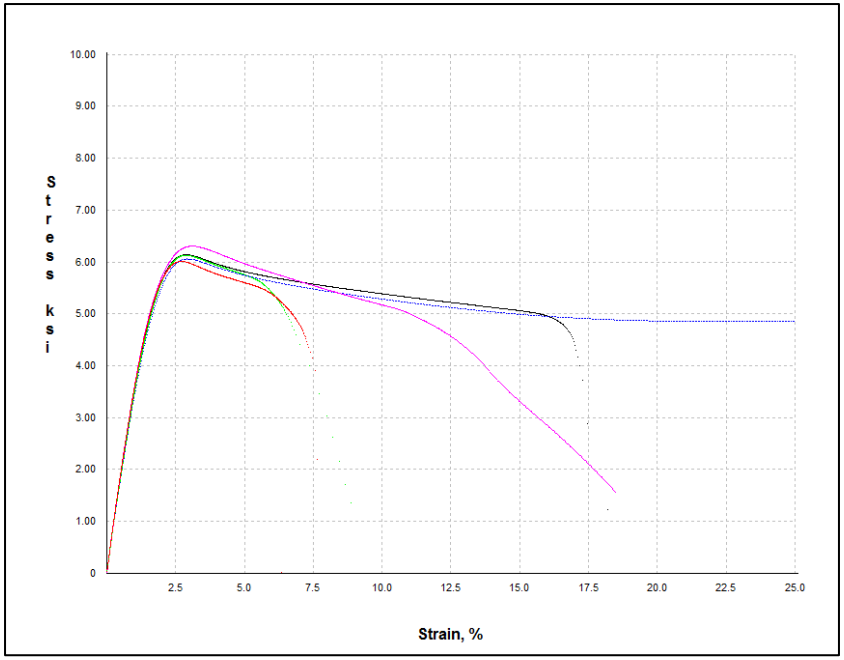
A few of the Key Findings from R&D Experience

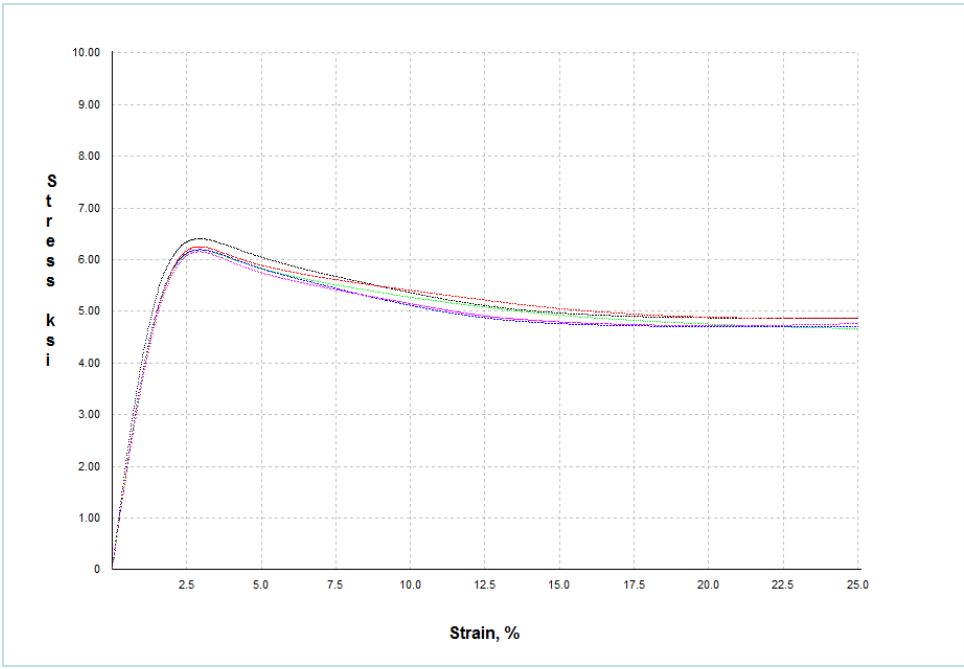
- PVC resin must be “Extrudable” in the Production Die
  - If PVC resin extrudes well in smaller dies or large dies with thinner walls **it does not follow** that the same PVC will extrude in the Nova die
- NOvA dies require powerful extruder
  - Big extruders have long heating volumes
    - Proper heating of PVC powder before it enters die
  - **Residence time is key** once inside the die
    - PVC will decompose if exposed to high temperatures
    - Burning & sticking to die
    - Some narrow openings will get clogged
  - **Long distance** to reach outside cells
  - **Thick walls & webs require higher mass flow**
- Extruding machine should operate at ~80% max capacity
  - Highest quality product

PVC Quality Control



Tensile Test Results





Typical Bad Results

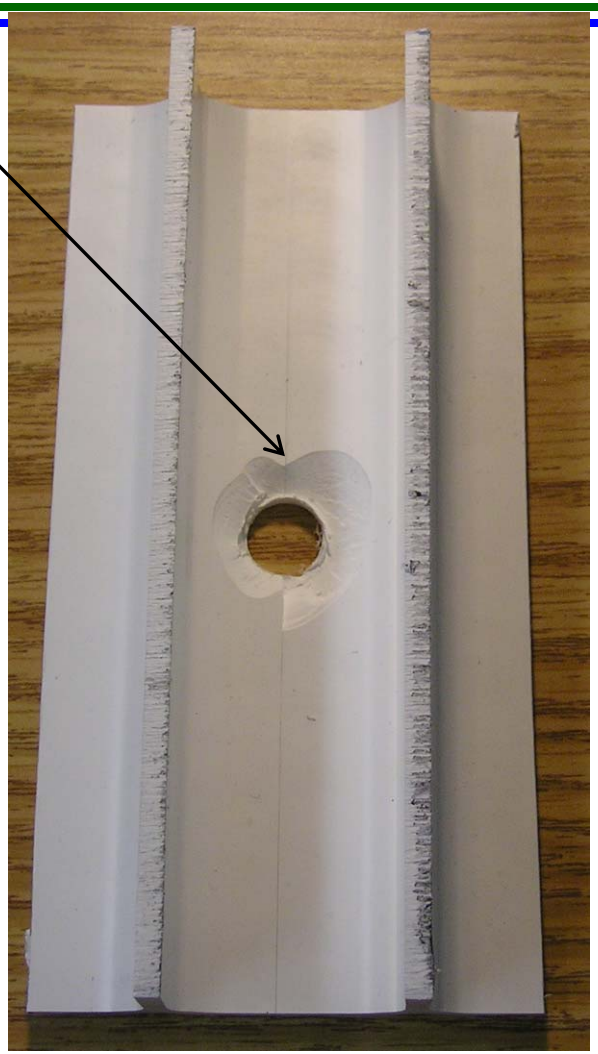
- Low total elongation, with lots of scatter.
- Yield stress at or below 6000 psi.

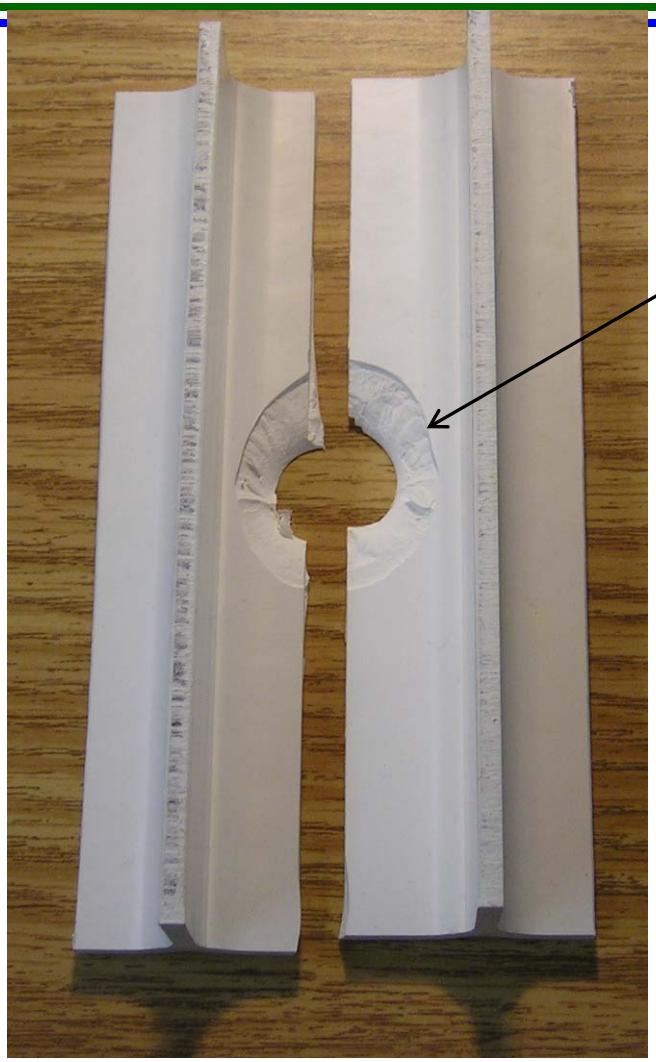
Typical Good Results

- Plots are consistent and very similar
- Large total elongation, typically all over 30%, many going to 50%.
- Yield Stress over 6000 psi.

Knitting problem

crack initiated here





underside crater