University of Washington, Seattle

- Experience with design and construction of CF structures for Silicon trackers
  - Worked on design and fabrication of a number of CF structures for the new Layer 0 of D0 Silicon Micro Tracker
    - Design and building of 3-d model of the structure
    - Fabrication of precision mandrels
    - Fabrication of the support structures and cooling manifolds
  - Worked on design of proposed Run2b D0 Silicon Tracker and had major responsibility for design and fabrication CF support structure for Layers 1 and 2
- Participants: Henry Lubatti (Physics), Colin Daly, Bill Kuykendall and Mark Tuttle (Mechanical Engineering)
  - Mark Tuttle has many years experience with CF work and a fully equipped CF lab with ovens and hot presses
  - Colin Daly has extensive experience with CAD design and FEA analysis
    - Performed all FEA mechanical and thermal studies for the Run2b structures and the recently installed Layer0
  - Bill Kuykendall did all of the material layup for the SMT support structures including developing a method for co bonding a Kapton-cooper mesh ground plane to the carbon fiber support structure

University of Washington, Seattle

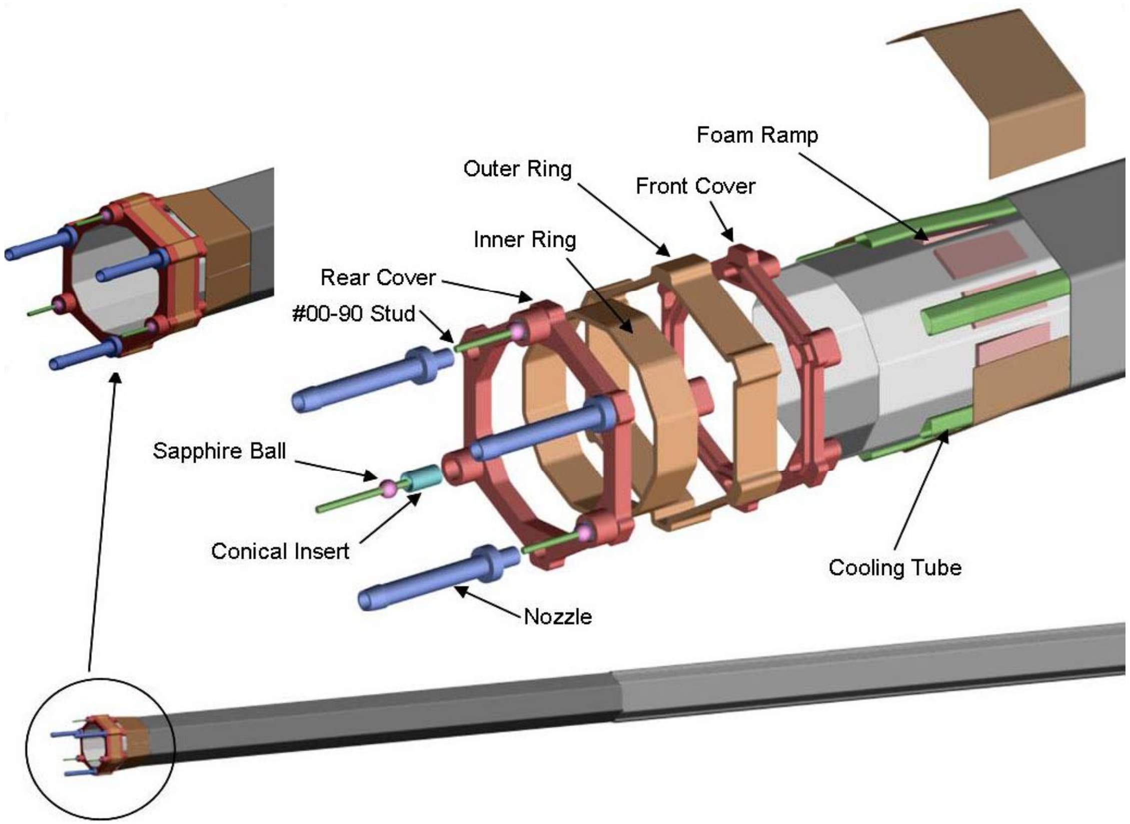
- **Resources**
  - Large Physics Department Machine shop with 6 full time instrument makers
    - Experience in fabricating precision mandrels for D0 Silicon Micro Tracker (SMT) CF support structures
    - Experience with machining composites
    - Equipment for evaluating finished pieces (CMM)
  - Extensive experience in fabricating CF structures for the D0 SMT (Run2b and L0)
  - Access to resources in the departments of Mechanical Engineering
    - Use of equipment for measuring mechanical properties
      - Universal Tensile testing machine
      - Strain gauge conditioning and recording equipment
      - Environmental test chambers
    - Mark Tuttle's lab in Mechanical engineering
      - Fully equipped lab for layup and production of CF structures
      - Access to Department of Material Science autoclave (60 cm diameter and 60 cm deep)

CAD Capability

- Unigraphics NX5 CAD/CAM Package.
- Very powerful 3-d modeling capability
- Complex assemblies easily created along with interference checking, exploded views, etc.
- Simple generation of engineering drawings
- Fully integrated to CAM operations so that machine shop can generate tool paths for CNC machining directly from the solid model
- Changes to solid model automatically update the tool paths

CAD Capability

- **Example of work done for L0**

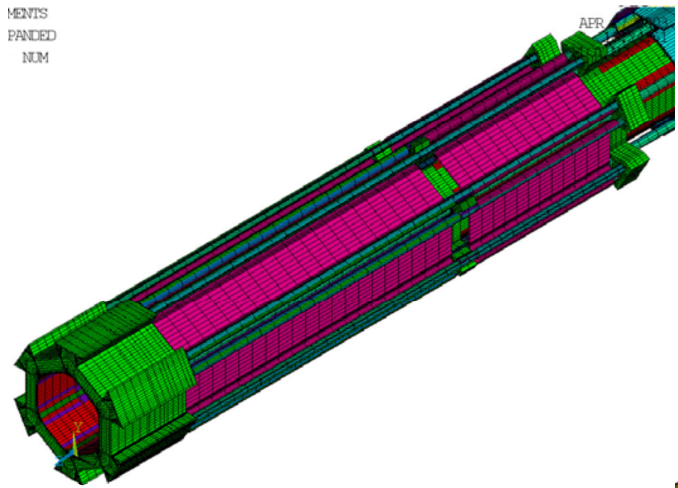


Finite Element Analysis

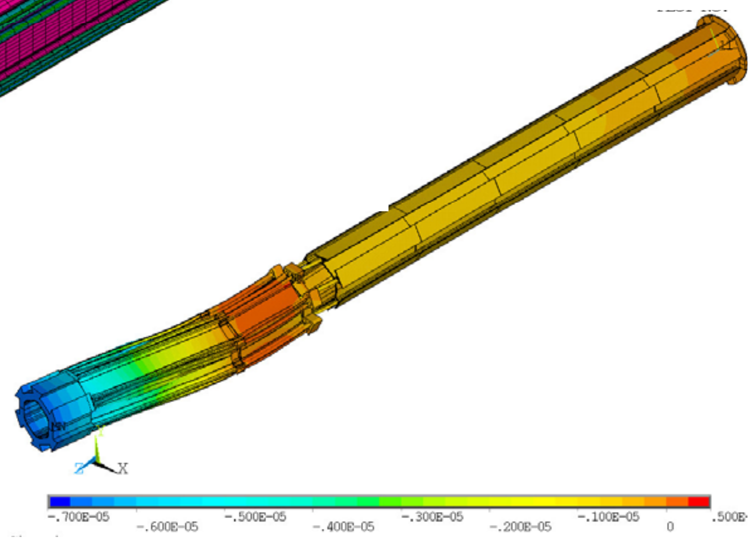
- Ansys version 11 FEA system research license
- No size limit on problem
- Carbon fiber/epoxy structures modeled with solid elements using orthotropic material properties
- Extensive experience with CF structures used in upgrades to layer 0 of the D0 detector at FNAL
- Used for design of all of the 436 end cap muon chambers for ATLAS at LHC

Finite element Analysis

- **Example of work done for L0**



FEA model of a proposed Layer 0 CF structure



Gravitational deflection of the structure

Physics Department Machine Shop

- Fully equipped Physics Department machine shop
  - Four CNC mills
    - One with one has 82 inch x-travel (about 2 meters)
  - Two CNC lathes
  - Many conventional mills and lathes
  - Wire EDM
  - Die sinker
  - Quality control equipment in temperature controlled room
    - Brown and Sharp coordinate measuring machine
    - Smart scope for small pieces
  - Full welding capabilities (TIG/MIG)

Mechanical Engineering

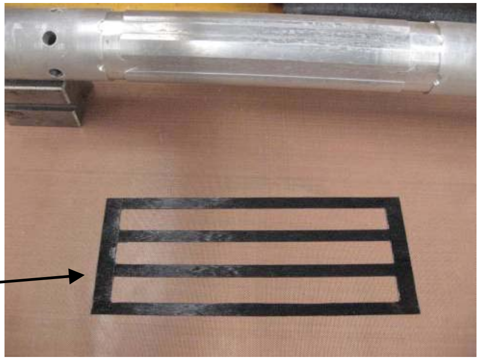
- Composites Fabrication
  - Hot press, 50 ton Tetrahedron, 35cmx35 cm platens
  - Lab Ovens (3), 250°C
    - 20in x 20” x 15”
    - 36” x 48” x 30”
    - 12” x 72” x 12” (MSE) 12” x 72” x 12” (MSE)
- Material Testing Lab
  - Instron load frames
    - 5585H 250kN capacity, static testing, tension/compression.
  - 8511 20kN capacity, static or cyclic testing, tension/compression
- Abrasive water jet cutter, 2-axis CNC, 48” x 48” table
- Universal testing machine for evaluating tensile properties
- Rapid prototyping facilities

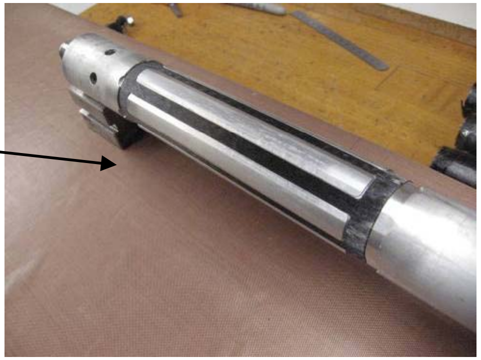
University of Washington - ILC detector

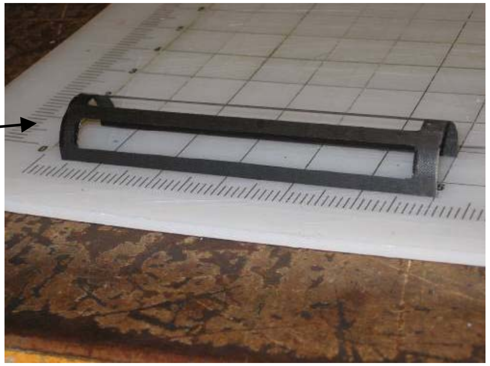
- The Seattle group has been working with Fermilab on the carbon-fiber mechanical support structures
  - Develop techniques for fabricating and handling thin-walled carbon fiber structures
  - Prototypes of carbon-fiber support structures
  - Various tooling for attaching support membranes to support structure and mounting silicon wafers on support structure
  - FEA analysis of mechanical and thermal behavior
  - Measurement of material properties of carbon-fiber lay-ups
- Fabricated and delivered to Fermilab
  - Three prototype half-shell structures for evaluation, testing and developing silicon mounting procedures
  - Assembly mandrel, end ring glue fixture and vacuum chuck for precision placement of silicon

Support Structure Proof of Concept

- **A simple mandrel was made to develop fabrication techniques for the proposed carbon fiber structure**
  - Material is pre-laminated on a flat surface. Then the windows are cut out leaving the frame.
  - The pre-laminate is then layed up on the mandrel, loaded into a vacuum bag, and cured in an autoclave.
  - Removing the cured part from the mandrel without breaking it is a delicate procedure, but we demonstrated that this could be done reliably.

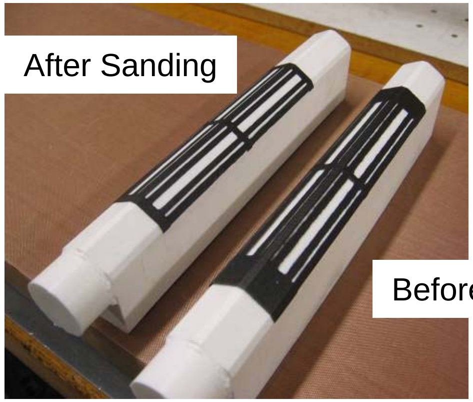






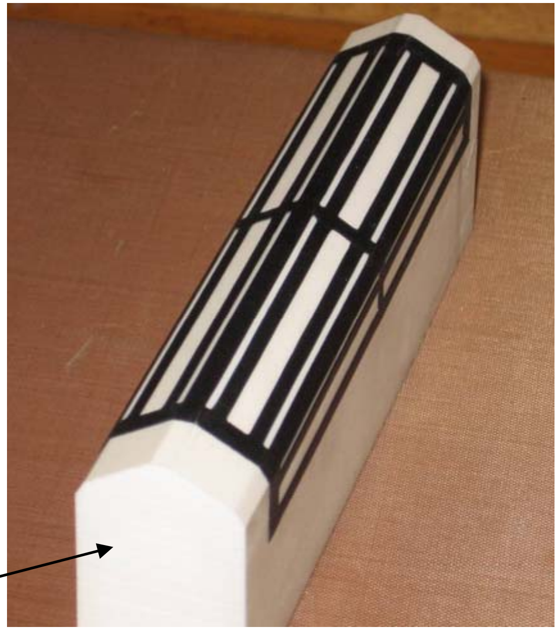
Layer 1 Prototype Support Structures

- **Fabrication techniques and mandrel design were refined for production of the prototypes**
  - **Windows are hand cut from the flat, uncured material using an aluminum template.**
  - **After curing, the window edges are cleaned up with fine sandpaper.**
  - **The ends are left long to maintain structural integrity during removal from the mandrel and while sanding the window edges.**
  - **A belt sander is used for the final operation of cutting the ends to length.**



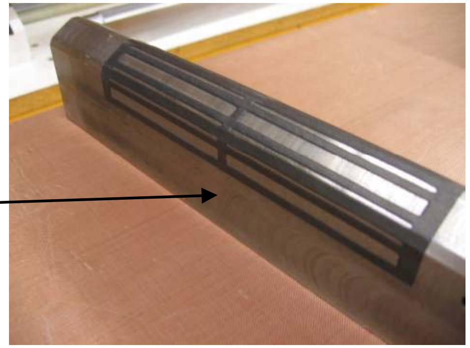
Layer 1 Prototype Support Structures

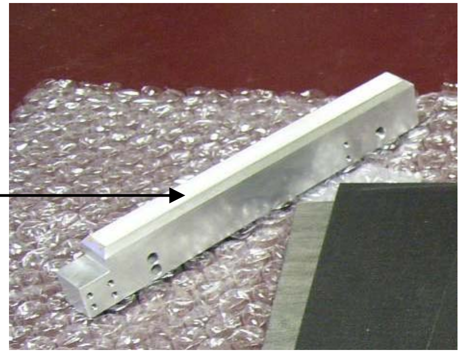
- Three structures made from K13C2U material
  - Fiber orientation is [0,90,90,0]
  - Next will do [0,90,0]
- Parts are delicate but reasonably robust if handled properly.
- Each structure is shipped with a handling mandrel (polyurethane castings of the lay-up mandrel).
- End-rings have been installed at Fermilab on one structure.

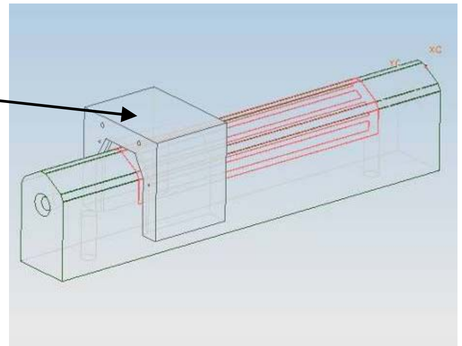


Tooling

- **Two identical steel mandrels were CNC machined.**
  - **One mandrel is used in Seattle for carbon fiber lay-up.**
  - **The second mandrel is used at Fermilab as an assembly fixture, and for mounting silicon.**
- **A vacuum chuck with a porous ceramic surface was fabricated. The chuck will be used to place silicon.**
- **Fixtures (2) for positioning of the end-rings during glue-up to support structure were machined. Fixtures are also used as support structure thickness gauges.**



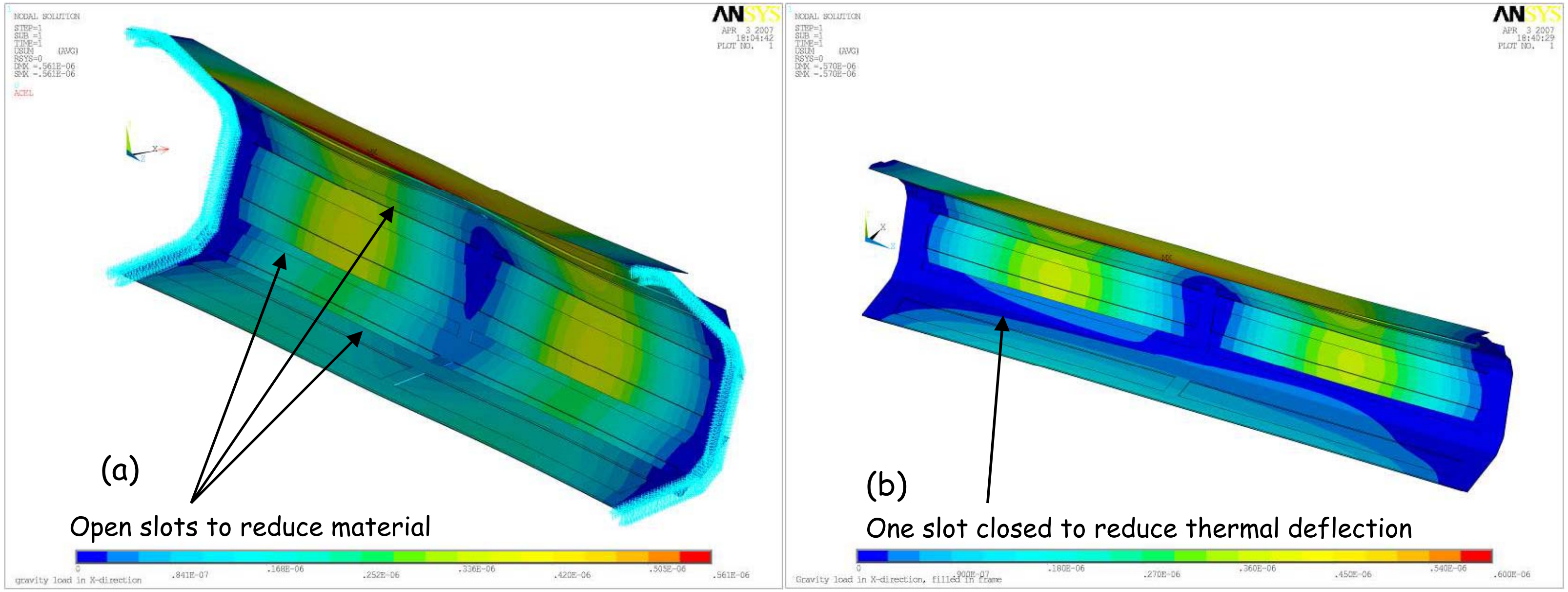




FEA Studies

This work has the aim of understanding how to optimize the geometry of the carbon fiber/epoxy composite frame to minimize deflection due to gravity and temperature changes.

This model uses a 4-layer (0,90,90,0 degree) lay-up. The gravitational deflections of two slightly different structures are:



The maximum deflection vector is about 0.6 μm in each case.

Measurements of Carbon Fiber Properties

- **Coefficient of Thermal Expansion measurements of [0,90,90,0] specimens underway.**
  - **Test method: Measurement Group Tech Note TN-513-1.**
  - **CTE measured using strain gages mounted front and back on flat coupons.**
  - **Coupons mounted in rack and placed in lab oven.**
  - **Thermocouples taped to each CF coupon.**
  - **Strain and temperature will be monitored**
  - **Dwell time at each increment will be 15 minutes minimum.**