Composite Materials for Low Mass Stable Structures

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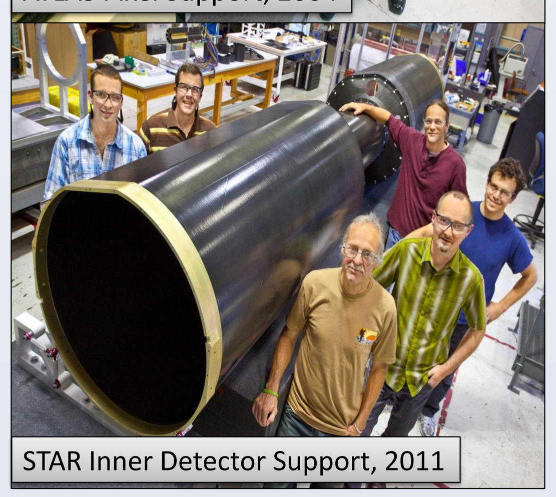
BERKELEY LAB
Lawrence Berkeley National Laboratory

Detector Supports for HEP Experiments

Tracking Detectors require support structures with low mass to reduce Coulomb Scattering of particle tracks thru the structure layers. Scattering and Stability detract from detector resolution equally. High Specific Stiffness materials E/X_0 are ideal for detector supports.


ATLAS Pixel Support, 2004


STAR Inner Detector Support, 2011

Global Supports and Integrating structures for Detectors are a core competency. These are typically thin-wall (0.6-0.8mm) cylinders, up to 8m assembled length. Eccentric stiffeners and mounts with composite bolted flanges are typical. Bonded Assembly procedures and tooling allow for precision of +/- 50µm

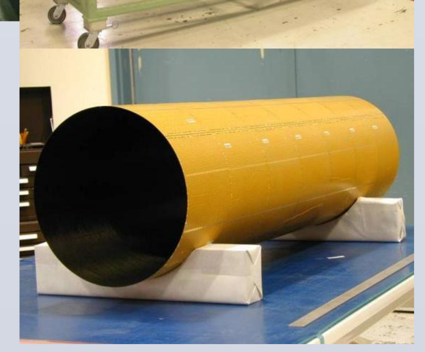
Supported Detectors are often 10X the mass of the support structure

Structures shown at left are used to both support and install multiple layers of Silicon Detectors around Be Beam pipes and are installed at the hearts of HEP/RNC colliding detectors

LBNL Composite Shop was established to provide structures for the ATLAS Pixel System in 2002. Since then we have provided structures to both upgrade projects at RHIC and continued R&D efforts for sLHC upgrade

Process Equipment

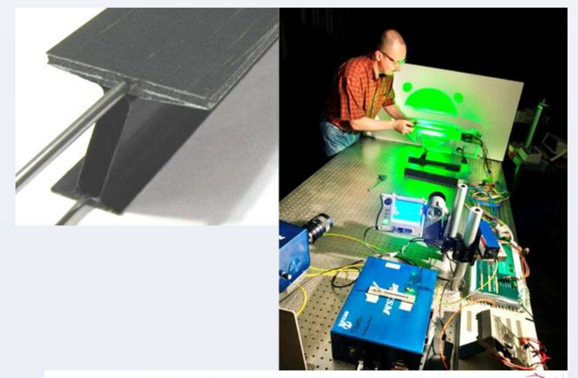
5X10 ASC Autoclave is fully automated, with integrated QC Database. Can process parts up to 1.2m X 2.7m, 150C cure temps with current pressurization system



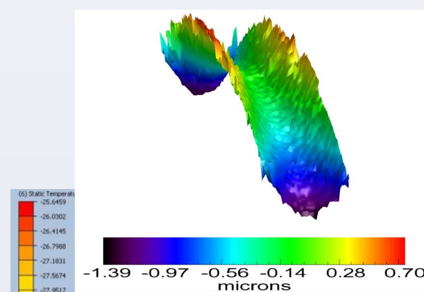
Automated Ply Cutter is used to minimize out-time of frozen Prepreg materials. Material/Part tracking DB links serial parts to production batches, tracks out-life and assures material remains in-spec—developed in-house by CAD Support Group

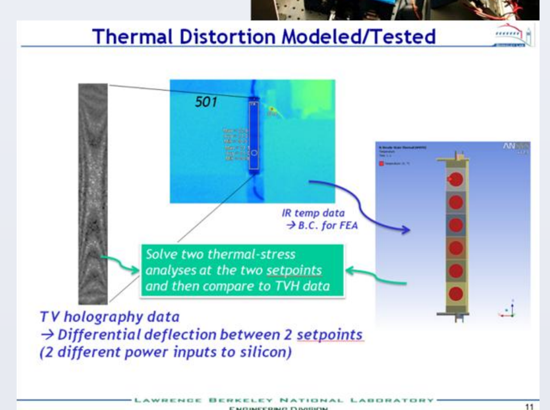
Structured Engineering Approach

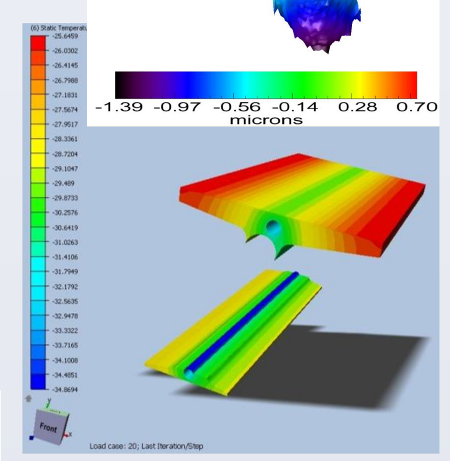
Scaled Prototypes are built and tested with thermal and structural loads and compared with FEM. Models are tuned and used to investigate options for full scale articles which are later built and similarly tested.

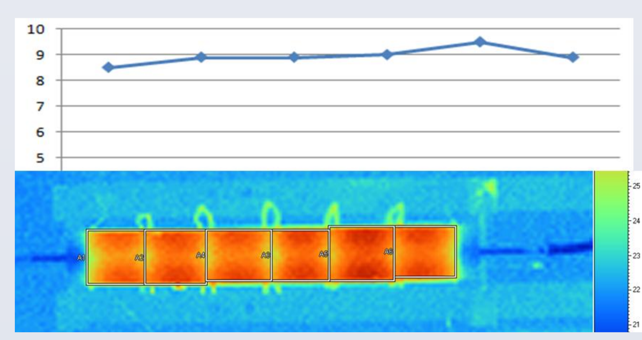


IR-Thermography and TV-Holography are integral to ability to deliver highly stable structures. Deflections from 5-50µm are typical for these measurements



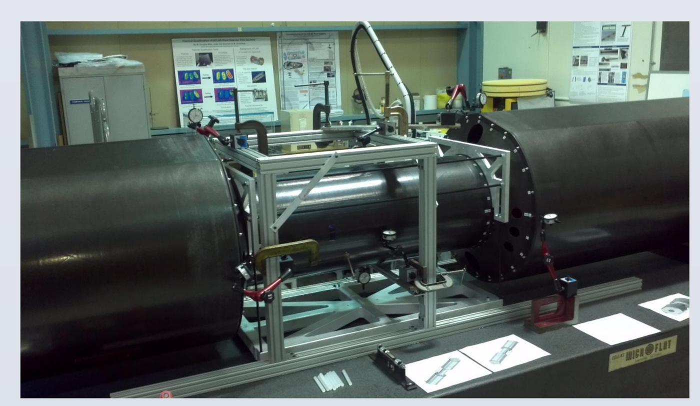




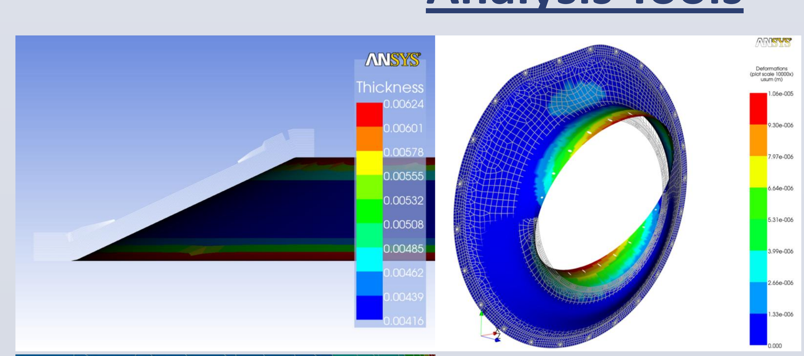


	Average ΔT	Range	Max to Coolant
A1	7.2	3.8	8.5
A2	7.8	2.8	8.9
A3	7.9	2.9	9
A4	7.7	2.7	8.9
A5	8.2	4.3	9.5
A6	7.9	2.7	8.9
Average	7.8	3.2	9

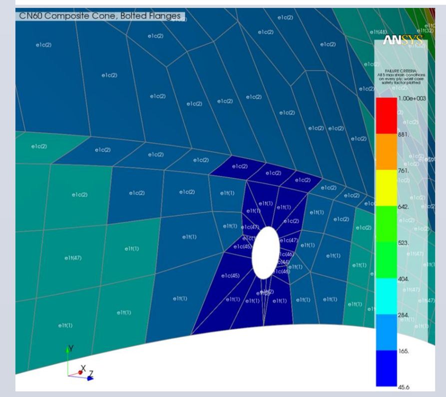
Load Testing of larger structures is equally important to tune FEM and trust reported Factors of Safety for critical lifts. Supported detectors are often multi-million dollar deliverables



Analysis Tools



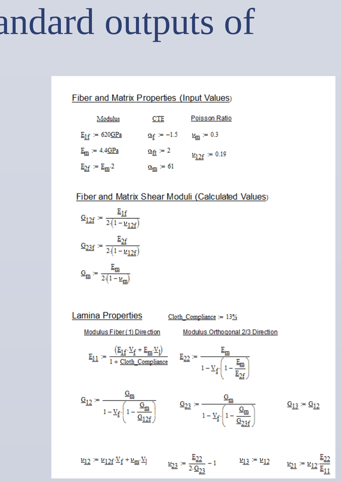
Cone Analysis showing Ply stack, Deformation and Fiber Failure plots



ANSYS Composites Pre/Post (ACP) used to input and analyze FEM results. Much more flexible and accurate than legacy or workbench modules which allow only ABD or orthotropic property inputs.

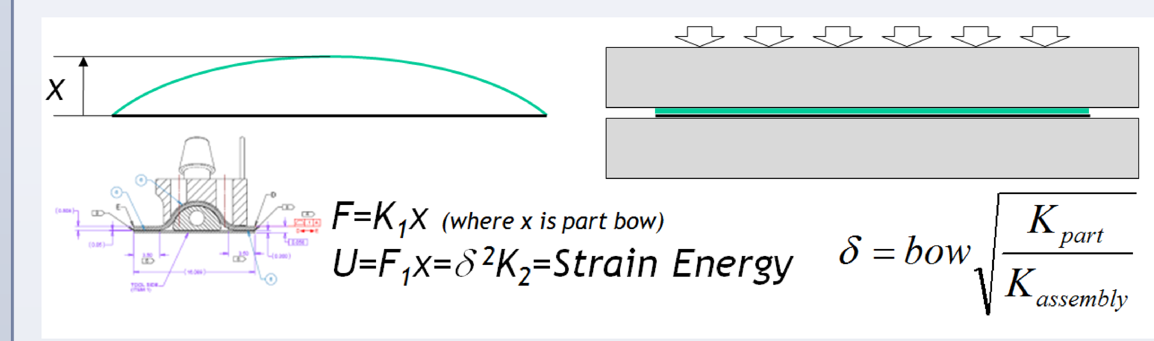
Direct ply input allows tighter control of fiber orientation and standard outputs of typical failure plots

Micromechanics, lamina properties, and correlation with sample tensile/bend tests use MATLAB/Mathcad

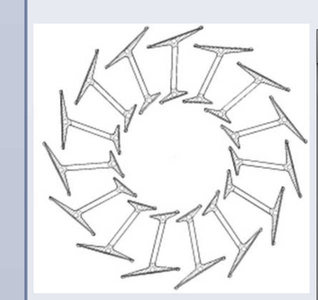


Fabrication and Assembly Interact

Detector supports have high geometric tolerances to allow placement of Si sensors and electronics, but must be thin. Post-machining to achieve accuracy is not typically possible due to material thickness. Parts/Assemblies must come off of the tool within tolerance

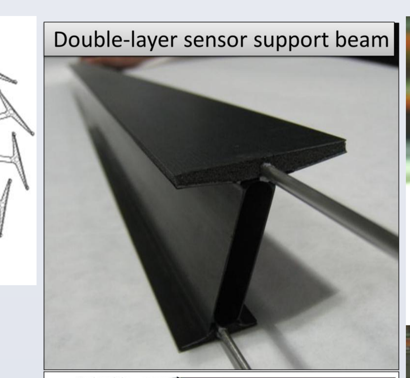


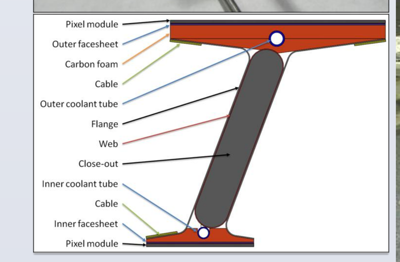
Original ATLAS Stave 'Omega' part required curved tooling to yield flat assembly due to high part sectional stiffness. Developed concept of low-stiffness parts bonded into high stiffness assemblies. Primary benefit is use of lamination tools as assembly tooling, reducing cost and iteration time (no need to develop curved tooling). R&D developed 1.2m I-Beam with flatness better than 50µm, with integrated Ti cooling channels. It is now the baseline for ATLAS Upgrade innermost layers

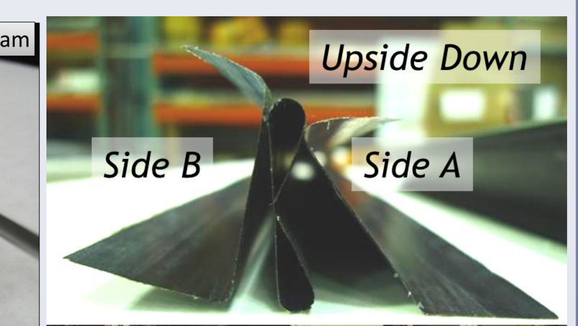


Parts are 4-ply unbalanced laminates that counter-twist

Each is under 100µm thick

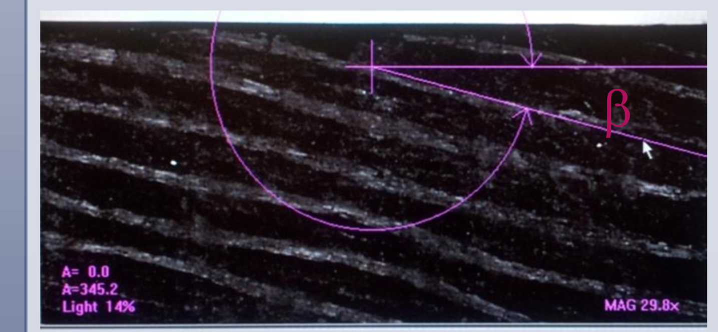

Double-layer sensor support beam

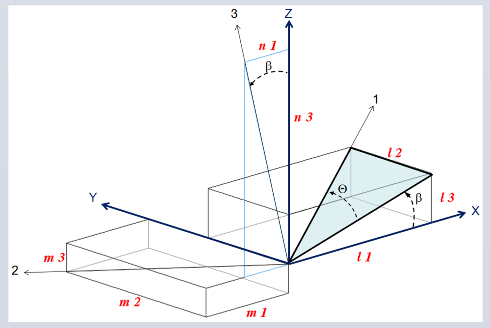




Material Development

Composite material properties are only beginning to be standardized for industrial use. The push is for intermediate modulus materials for strength driven designs (airframe structures). We typically use Ultra High Modulus fibers common to satellite structures. Functionally every order is a custom material, and fabrication methods can yield unique properties.

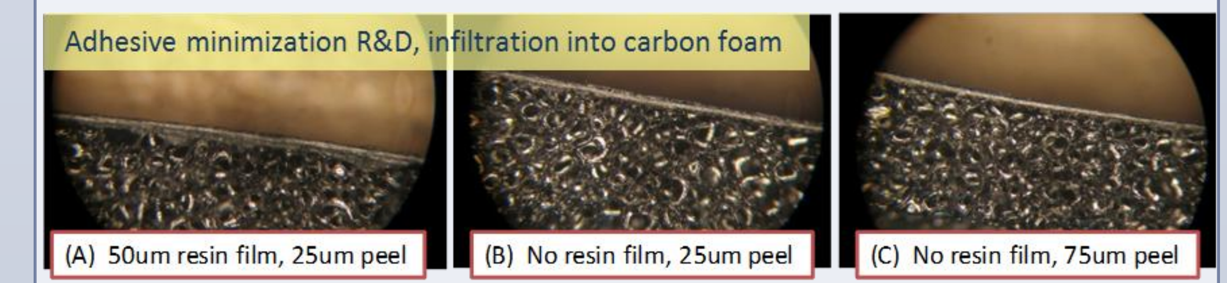




UHM CFRP is used both for its stiffness, but also it's thermal conductivity. Thru thickness conductivity is desirable for some thermal applications. Use of CFRP versus C-C (Carbon-Carbon) has potential cost benefits and schedule flexibility. Currently prototyping inclined plane laminates, and developing micromechanics via testing.

Process Optimization

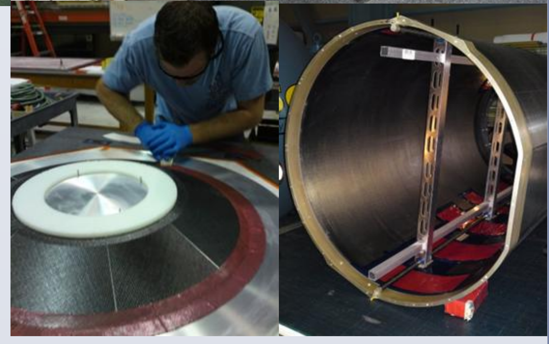
With laminates approaching the thickness of a typical bonded joint, adhesive mass is important to control for low mass structures. Resin content of custom prepregs can be tailored to allow co-cured components with no additional adhesive. For some of these low mass structures, adhesive can be 30-50% of the overall mass if not well controlled.



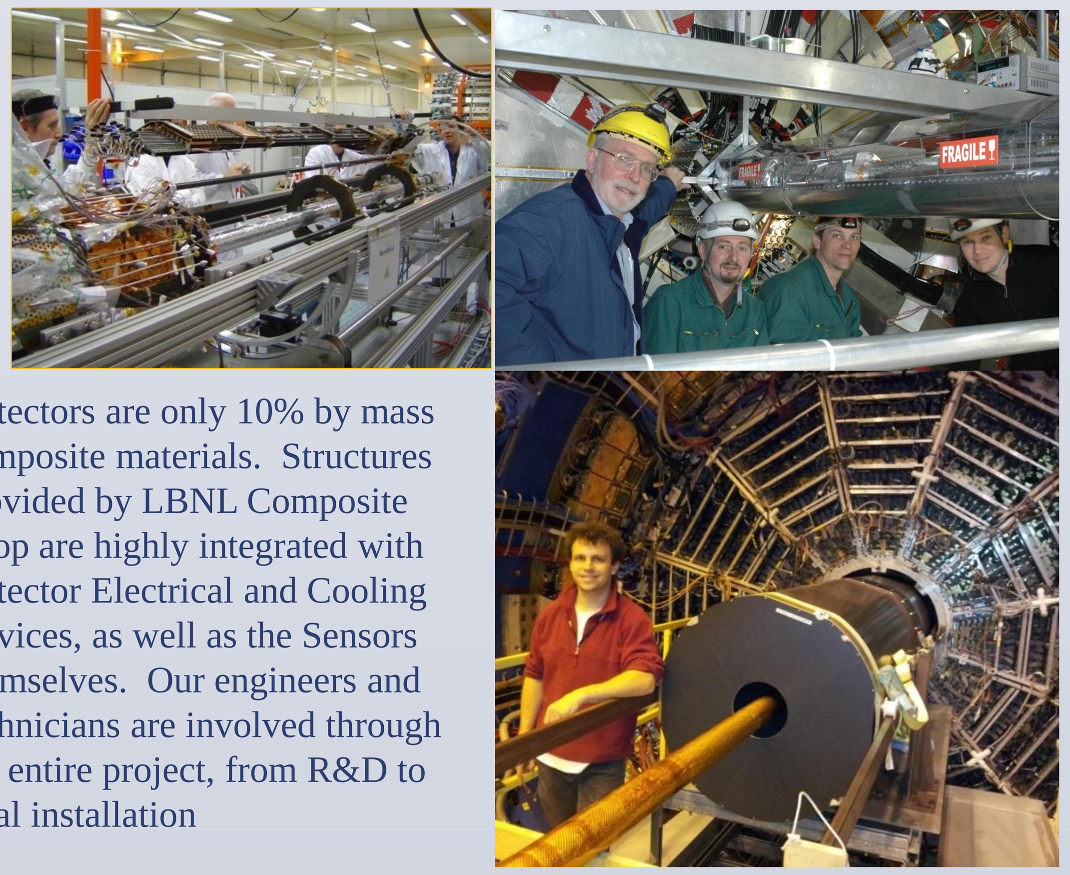
Tooling Design and Fabrication

A combination of in-house and nearby machining capability is used to deliver and modify tooling for lamination and assembly tooling

Use of common tooling components across multiple assemblies allows for precision, and self-referencing features machined into sub-components. Minimizes tooling cost while maintaining required precision



Integration and Assembly



Detectors are only 10% by mass composite materials. Structures provided by LBNL Composite Shop are highly integrated with Detector Electrical and Cooling services, as well as the Sensors themselves. Our engineers and technicians are involved through the entire project, from R&D to final installation

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