Design Concepts and Support Structure

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HYTEC

Global Supports and Related Components

- Topics--focus on answering some questions
  - What do we mean by Global Supports?
  - What do we mean by Local Supports
  - What are the design issues in Global Supports?
    - what are the interface issues between local and global?
    - What is the interface issue between Pixels and SCT, as related to supports
  - What is our approach to addressing or solving these issues?
  - What is the status?
    - design calculations?
    - costing?
    - prototypes?
  - What are our near term objectives?

Global Supports

Metrology Frame for Supporting Detector Elements *(Ultra-stable System)*

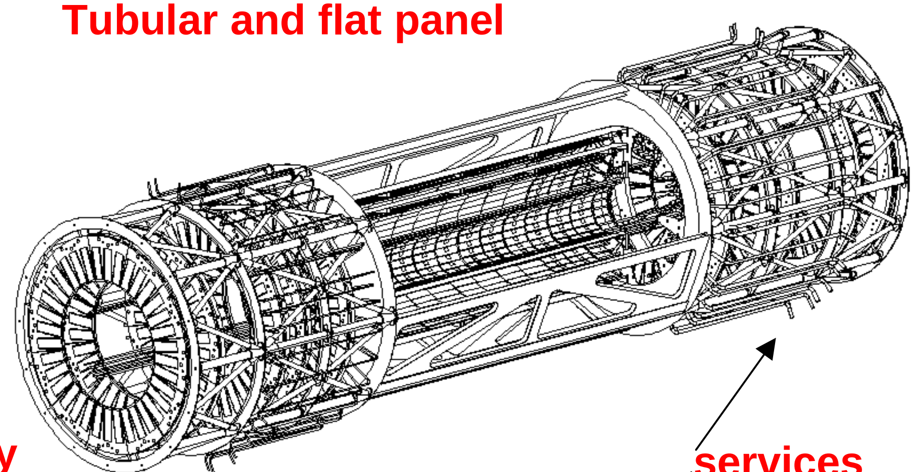
- **Definitions**
  - Pixel modules are mounted on *local supports*
  - *Local supports* additionally serve as thermal structures for cooling
  - Overall frame structure onto which the local supports are mounted is referred to as the *Global Supports*
    - the mounting interface between the local and global supports, for the purpose of this discussion are *related concepts*
    - *more general definition would be kinematic mounts used to interface the local supports*
- **Involvement**
  - US recognized as taking a lead role in Global Supports
  - Started with Pixel Detector Collaboration authorizing study to define approach-*for the TDR*
    - jointly supported by Germany/Italy/US

Initial Design Study

- **Scope of support study**
  - **Outer and inner frame structures, providing support for barrel and disk regions**
  - **Frame concepts**
    - **outer--tubular, shells, and flat panel, also combination of tubular and flat panel**
    - **inner--shell, full and half shells (clamshells)**
  - **Limited to analysis and preliminary costing to define selection**
- **Results used in TDR--*important aspect of study***

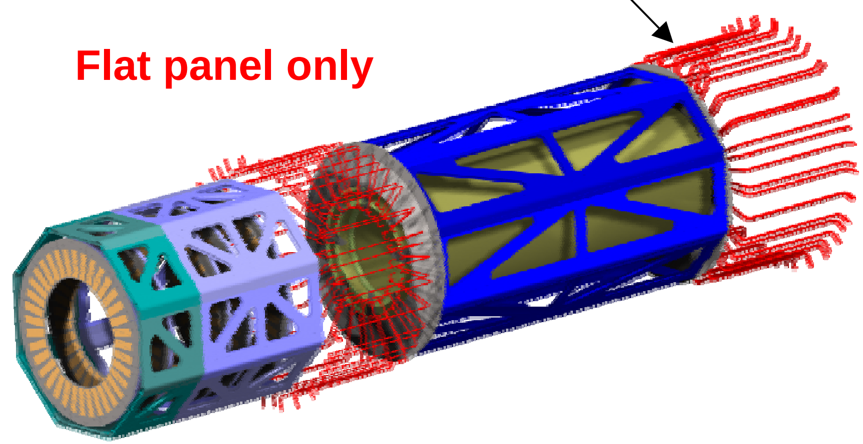
Frame Examples

Tubular and flat panel



services

Flat panel only



Both use end cones as support for inner barrels

Primary Design Issues

Structural Issue

- **Stability**
  - **Short and long term < 10 μm's**
  - **Stability considerations**
    - **thermal, ΔT of >40°C, or more**
    - **dynamic, structural vibration- *design envelop not well defined***
- **Material limitations/Radiation length**
  - **High stiffness to weight ratio structures-- *forces stability issue***
    - **support detector mass ~6 times structural weight**
  - **< 0.36% normal incidence-- narrows options to low Z materials**
- **Interface to SCT--mounting concept influences dynamic stiffness**

Cost Issue

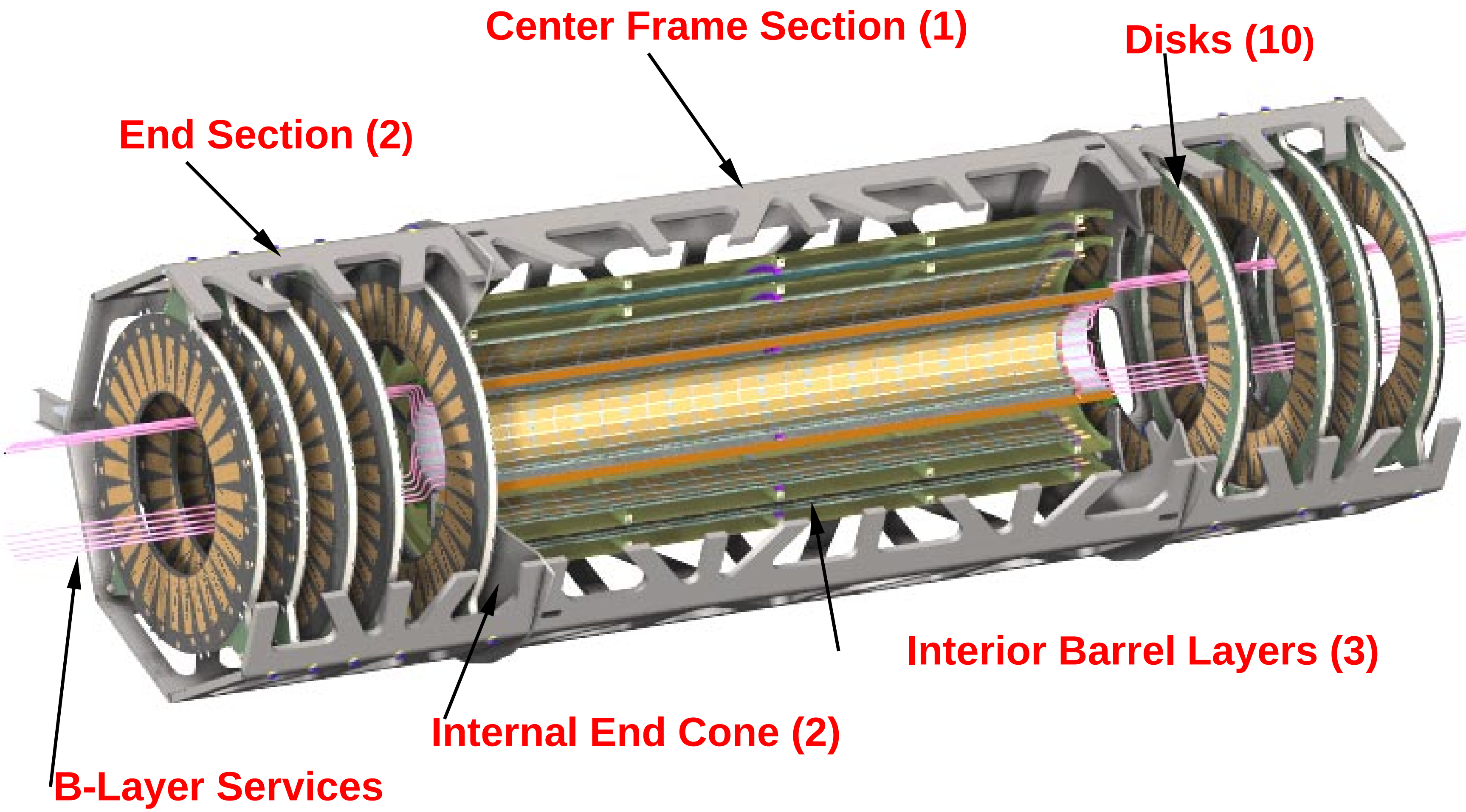
- **Structural design approach-Driven by *Build to Cost***

Primary Design Issues

Response to design issues

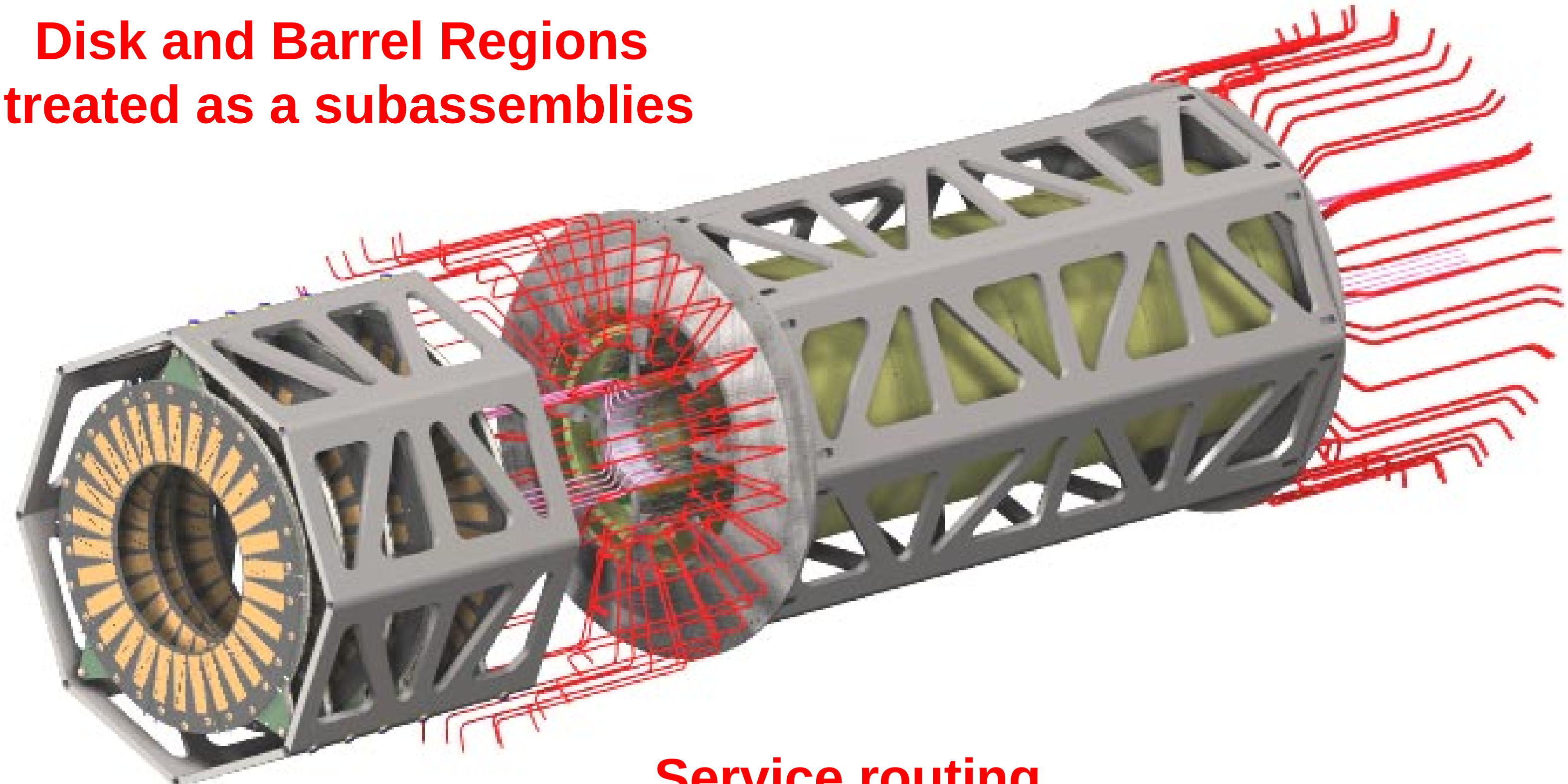
- **Material**
  - Low moisture sensitivity, low expansion composite material
  - Disadvantage, thin prepreg material expensive
- **Construction techniques**
  - Dropped tubular frame because of cost issue
  - Selected clamshell for barrel region
    - staves installed on inner diameter, facilitated installation
  - Sandwich structures for outer frame and end cones
    - ultra-lightweight, high stiffness/weight ratio
- **Modular design**
  - Center-section, fully assembled barrel region
  - Disk regions mount onto center-section
- **Pixel Detector mounting**
  - Four point connection to SCT--*factor still driving the design*

Global Support Concept



Exploded View of Pixel Detector

Disk and Barrel Regions treated as a subassemblies



Service routing around end sections

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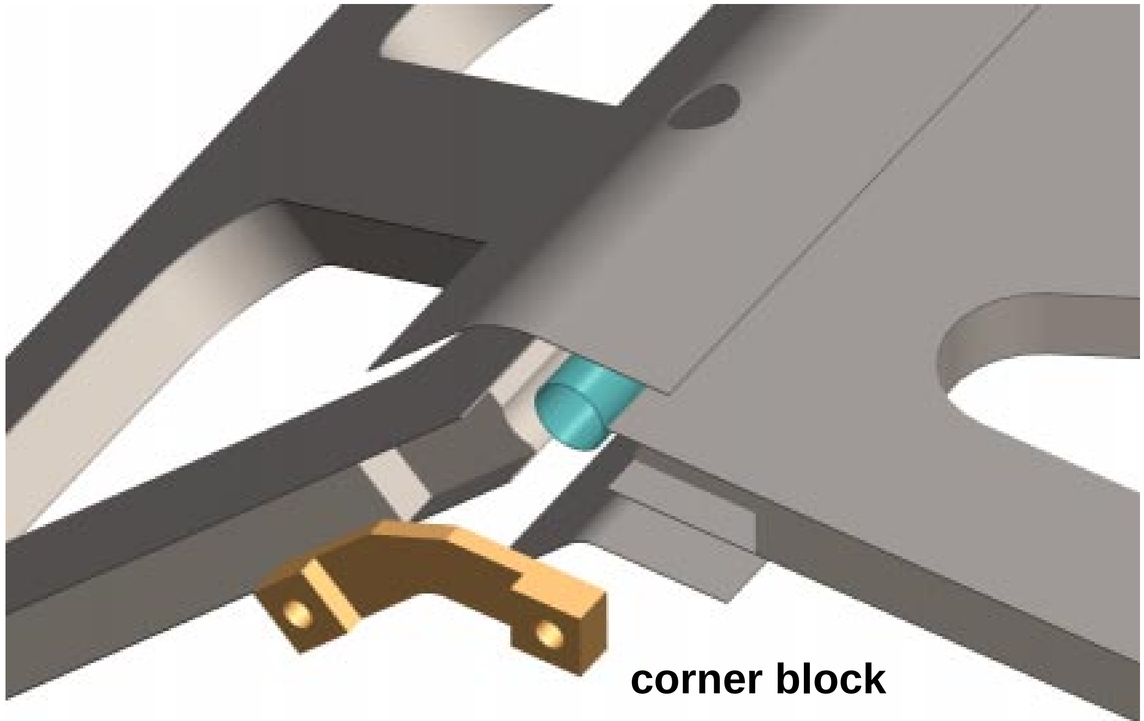
Construction Concept

Octagonal Frame Assembled Into Flat Panel Array

Flat panel Sandwich



Exploded corner detail

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Structural Considerations

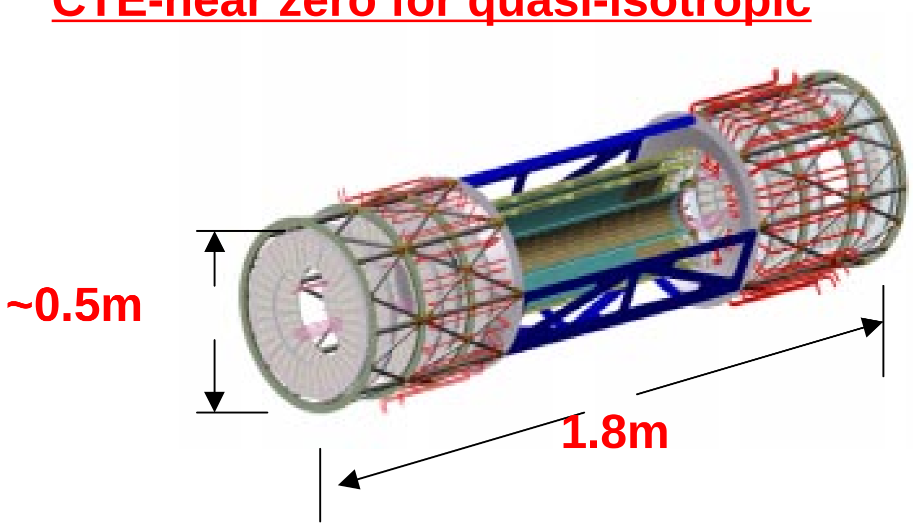
- **Composite sandwich panel-decision points**
  - facing material, e.g., optimum thickness and tensile modulus
  - core material, e.g., thickness, shear modulus, and strength
  - simple fabrication concept for sandwich
    - honeycomb versus carbon foam for core
  - load transfer
    - within frame sections
    - between panel sections in a frame section
  - provide load bearing support for local support elements
  - optimum cut-out geometry for mass reduction
- **Approach**
  - prepared design concept drawings defining structural approach
  - all aspects finite element modeling fairly complete
  - prototype testing next step

Frame Materials

XN50 or M55J Fiber With Cyanate Resin

CTE=coefficient of thermal expansion

CTE-near zero for quasi-isotropic



Conditions:

40°C temperature change

-0.25 <α<+0.1 ppm/°C

Result

0 to 9 μm's for 0.9m length

CME=coefficient of moisture expansion

CME is a function of Relative Humidity (RH)

Quasi-isotopic laminate data

105 ppm/%moisture exchange

Conditions:

assume moisture pick-up @ 55% RH (0.18%)
Frame members reject moisture to dry gas

Resulting contraction

~17 μm for 0.9m length

Comparable magnitudes

Strains induced are within the realm of construction tolerances

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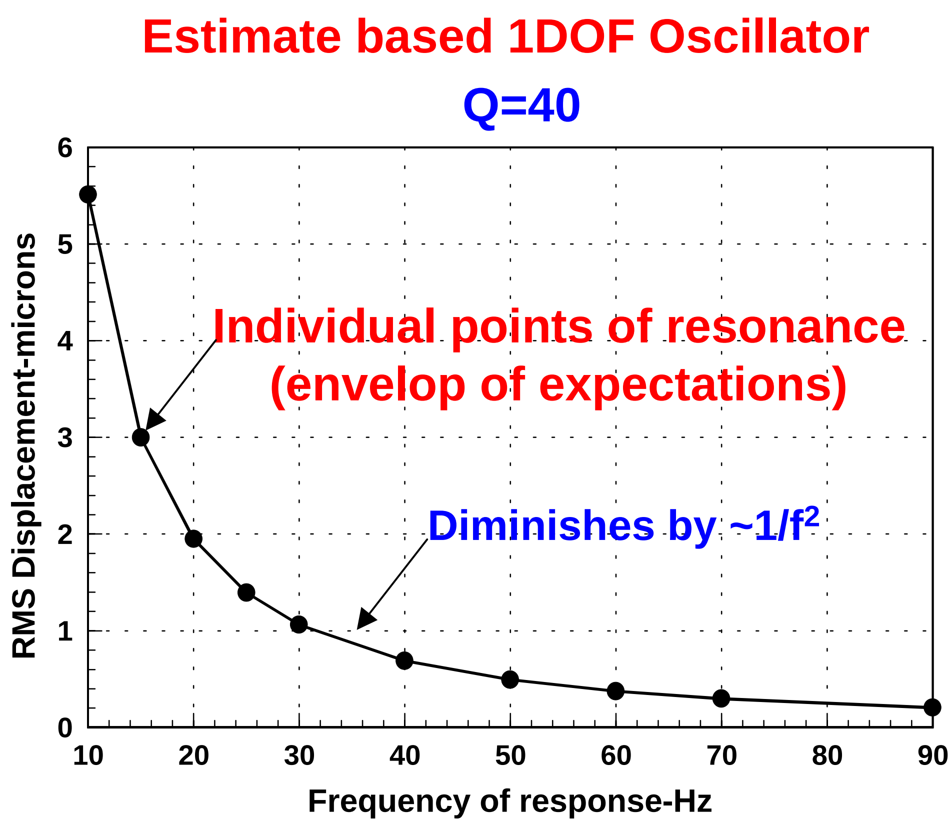
Dynamic Stiffness

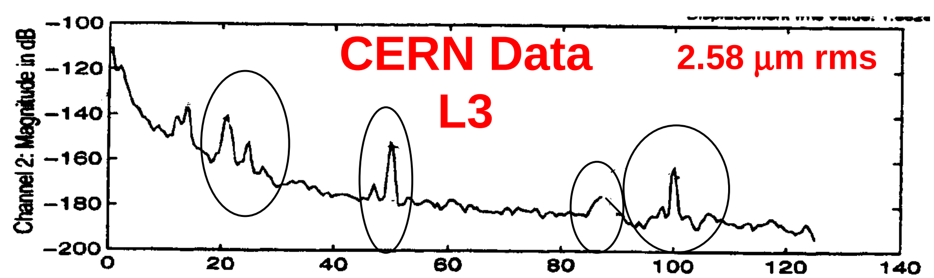
- ***Global Supports Approximation***
  - Random acceleration: PSD- estimated from CERN report

    4.85 10^{-9} g^2/Hz
  - A fundamental mode at 75 Hz would have a relative response of ~0.3µm rms, 1 sigma
  - Would appear vibration is not a design issue, *but:*
- ***A Potential Problem Exists***
  - *Discrete frequency spikes*

    of ≈ 0.25 µm will potentially result in >10 µm motion

  Impetus for $f_n \geq 70$Hz





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Core Material Evaluation

RTV Carbon Foam-3% Weight Density
(Shear Property Determination)

32 cm square sandwich tray
for silicon tracker

Carbon foam shake tests @ HYTEC

Foam core 30 mm deep
overall structure Q=50

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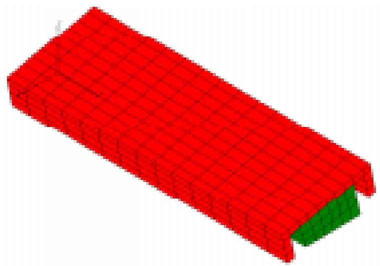
Issues in Core Materials

Shear Modulus Half of Published Values

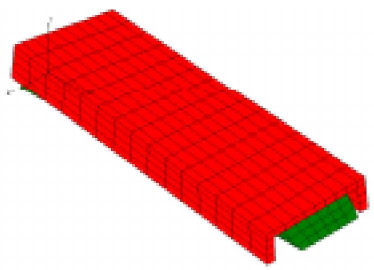
Measured
Shear Modulus
G=15.11MPa (2100psi)
Loss Factor 1%
Q≅80 to 100

Mode #	experimental freq. (Hz)	FEM freq. (Hz)	Model error (%)
1	370	396	+7.0
2	451	452	+0.2
3	537	527	-1.9
4	571	556	-2.6
5	~809	751	-7.2
6	~835	863	+3.4
7	~862	876	+1.6

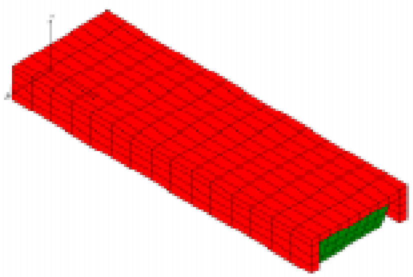
Mode 1: 396 Hz
roll and transverse shear



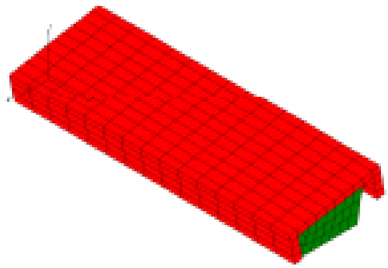
Mode 2: 452 Hz
yaw

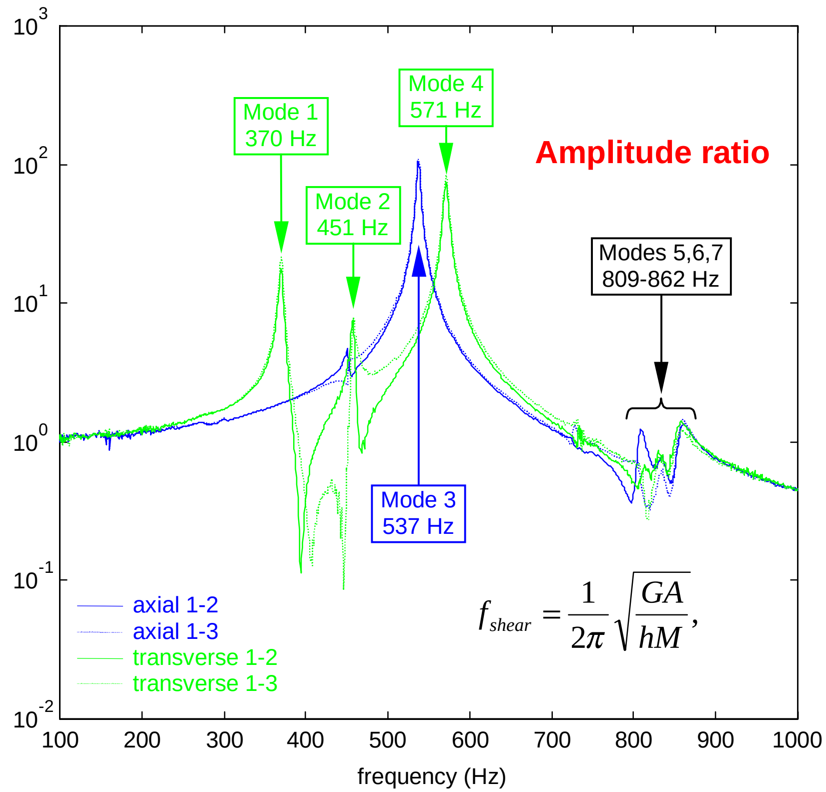


Mode 3: 527 Hz
longitudinal shear



Mode 4: 556 Hz
roll and vertical stretch





Global Supports 14

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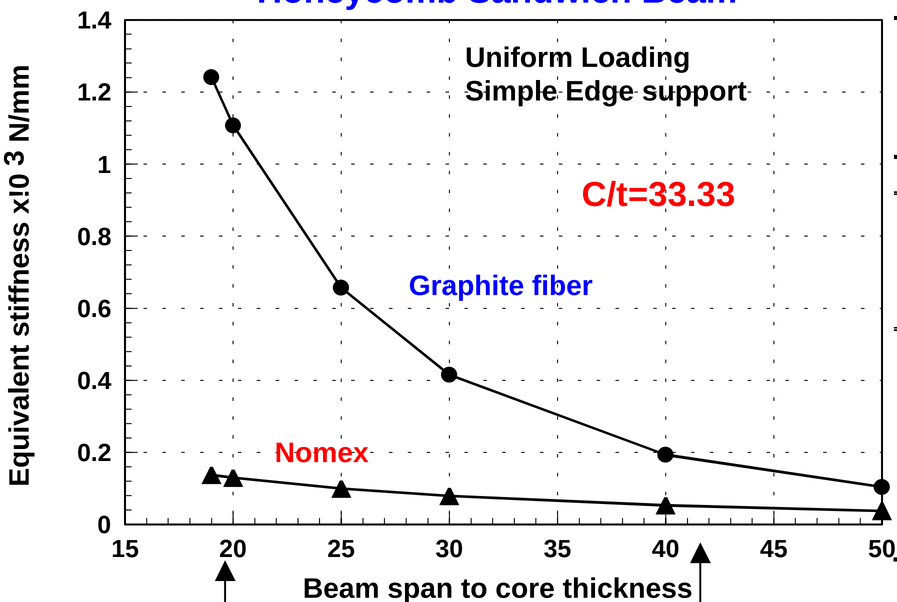
Sandwich Core Material

At 6% Solid Fraction RTV Carbon Becomes an Option
however
Graphite Fiber Honeycomb Is Superior

Honeycomb Sandwich Beam



Material	Shear Modulus L-dir N/mm^2	Shear Modulus W-dir N/mm^2	E/G L-dir	E/G W-dir	Density kg/mm^3	Material R_L mm	Core R_L %/mm
Honeycomb							
Aluminum	469	207	231	523	7.1E-08	88.9	0.030
Graphite fiber/epoxy	669	214	162	506	6.4E-08	250	0.015
Aramid fiber/phenolic	54	32	2013	3340	6.4E-08	300 est.	0.016
Nomex coml. grade	32	24	3413	4485	4.8E-08	200 est.	0.018
Foam							
Carbon foam (3%)	15	15	7078	7078	4.5E-08	285	0.011
Carbon foam (6%) est.	60	60	1770	1770	9.0E-08	285	0.021
Rohacell foam1	29	29	3733	3733	7.5E-08	5227	0.018
	50	50	2165	2165	1.1E-07	3836	0.026

E=10.83E+04 N/mm^2-Used as composite facing reference

- frame panel

- sector ring
- frame section

Corresponding points

To limit shear deflection in short beams use high G

In large span structures core shear deflection is negligible

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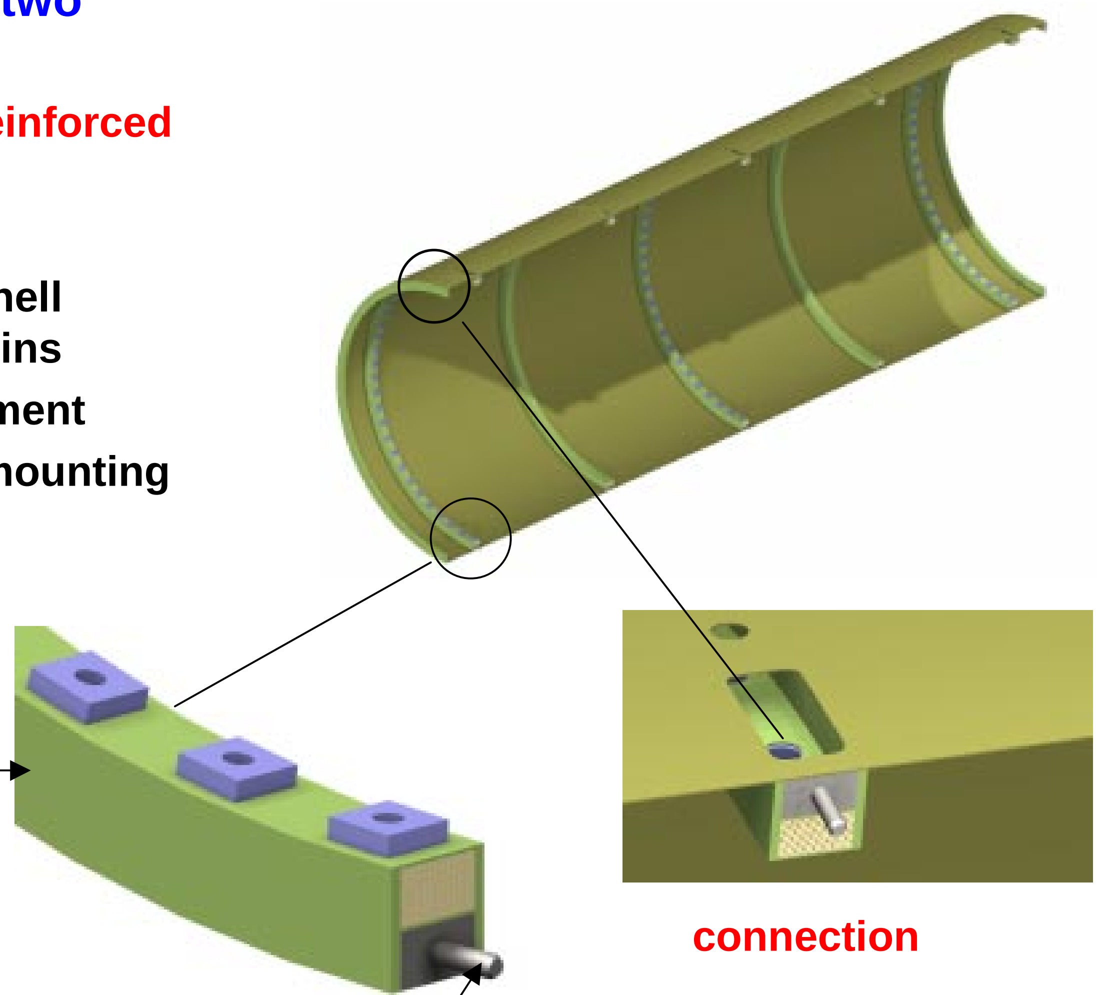
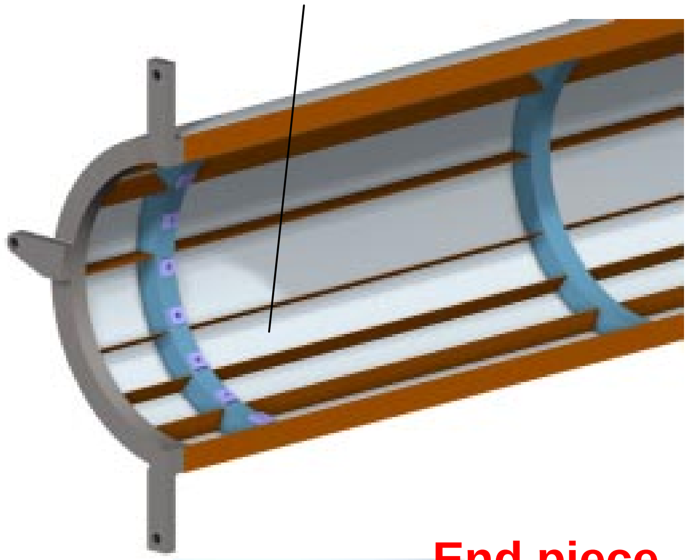
Barrel Global Supports

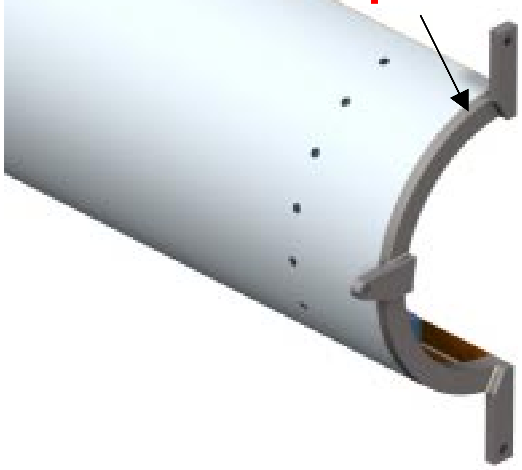
- **Clamshell concept-outer two layers**
  - single laminate layer, reinforced with internal rings
  - internal rings used for:
    - alignment of two shell halves-alignment pins
    - mechanical attachment
    - pockets for stave mounting interface



B-Layer Global Supports

- **B-Layer Clamshell Concept**
  - ***sandwich*** **structure, with longitudinal ribs**
    - ***initial concept*** **did not permit joining two half shells together**
  - **insertion of B-layer assembly after pixel detector in place**
- **Design options under study**
  - **Beam pipe support only at one end**
    - **greatly simplifying installation of B-layer**
  - **Permits clamshell assembly similar to outer layers**





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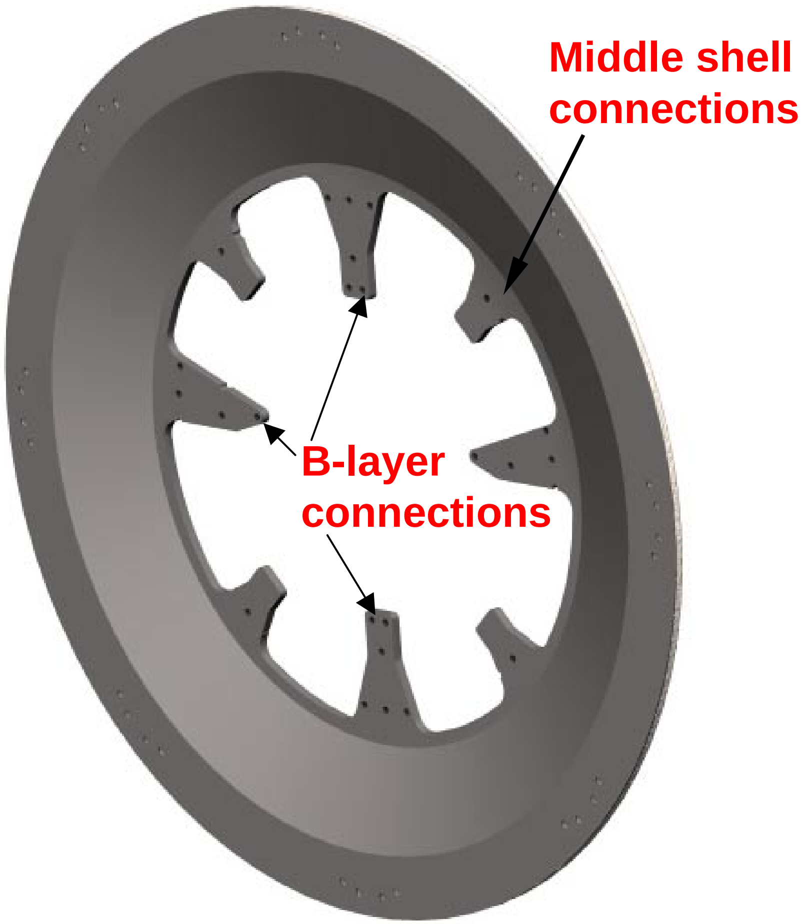
Barrel Global Supports

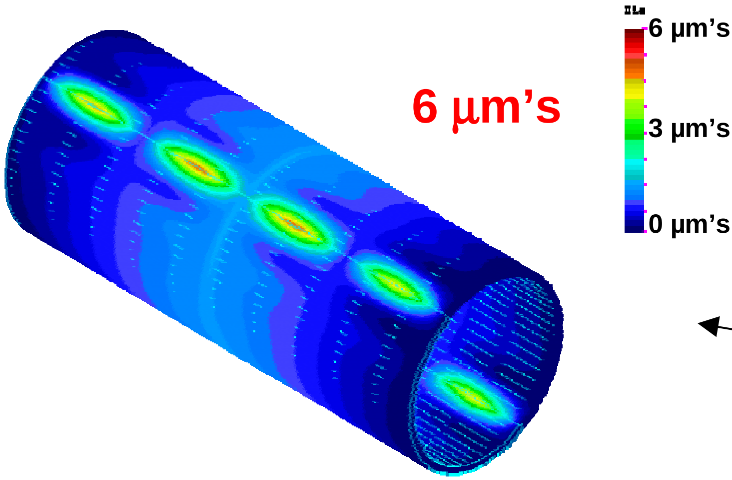
- **End Cones-*Barrel support***
  - Sandwich structure
  - Core thickness 4 mm
  - Thin prepreg laminate facings
  - Inner array of fingers provide attachment points for middle barrel shell and B-Layer shell
- **Service routing**
  - Cooling tubes penetrate the supports for the shells
  - Cabling routed around the inner fingers
  - Axial offset of 40 mm provides some flexibility to route around shell support points.



Barrel Region FEA Results

Examination of Basic Concepts

Individual FEA solutions

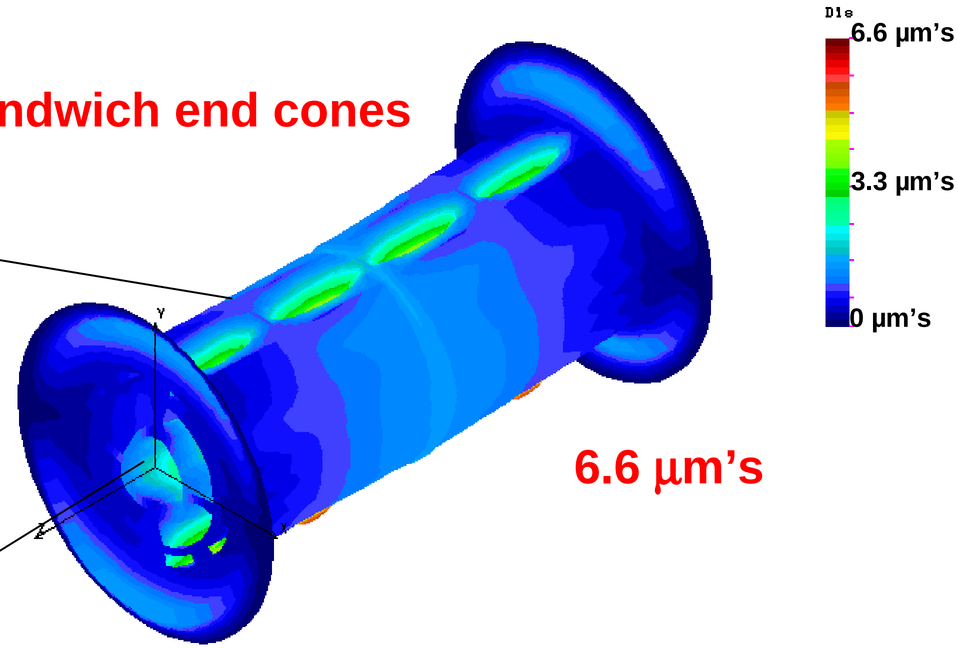


6 µm's

Outer Clamshell

Combined Solution
Including effects of End Cones

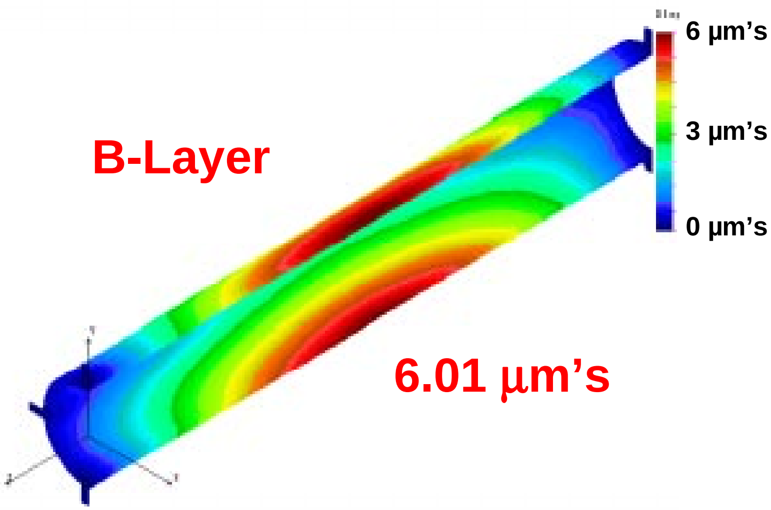
Sandwich end cones



6.6 µm's

Mass of Stave/modules-8.7 kg's
Structure 1.98 kg's

B-Layer



6.01 µm's

FEA Mass Breakdown

Item	Frame mass-kg	Added Structural mass-kg	Non-structural kg	Total mass-kg
Outer Frame				
Center Section	1.219			1.219
End Section	1.986			1.986
Disks/cabling/cooling			23.24	23.24
End Reinforcement	0.085			0.085
Corner Tubes	0.20			0.20
Barrel Region				
End Cones	0.30			0.30
Inner Shell(s) Support	0.12			0.12
Outer barrel shell	0.46		4.43	4.89
Mid-shell		0.52	3.15	3.67
B-Layer Shell		0.47	1.35	1.82
Total	4.37	0.99	32.17	37.53

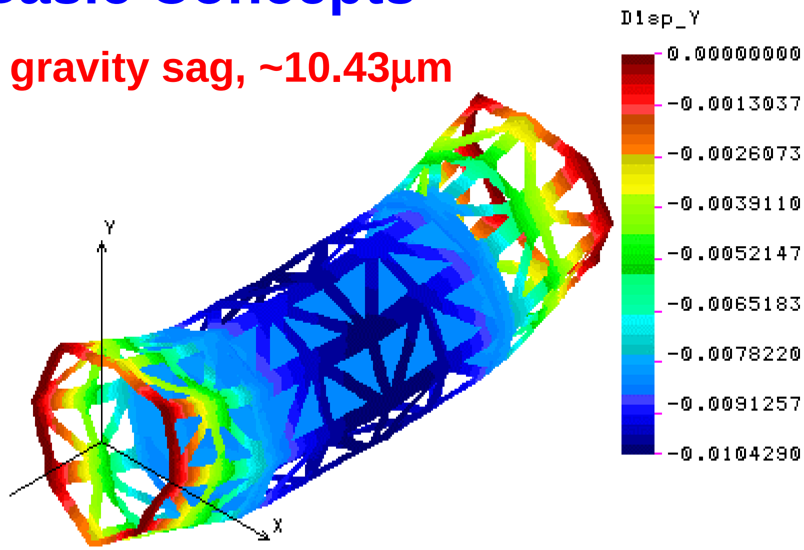
Total structural mass ~5.36 kg

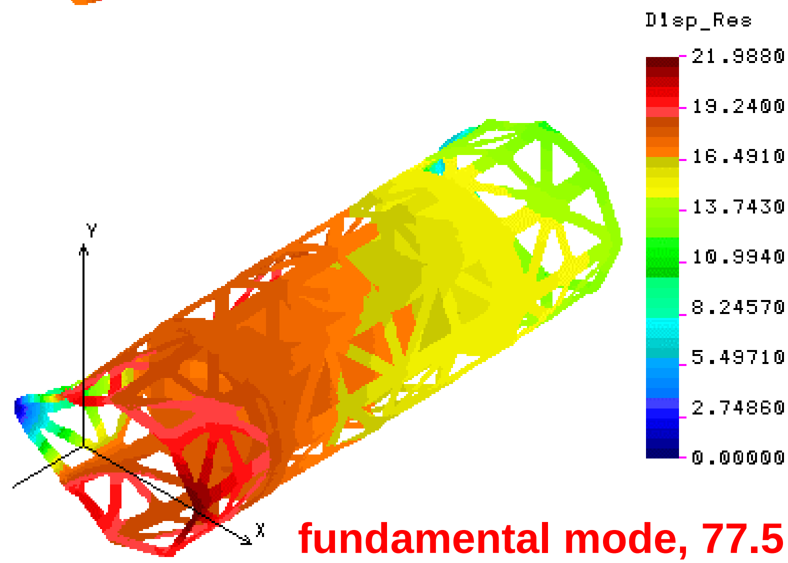
Frame FEA Results

Examination of Basic Concepts

- **Design status**
  - **Met static and dynamic stiffness design goals**
  - **Solutions based on expensive high modulus fiber systems**
    - **cost impact being evaluated**
  - **Reinforcement at detector ends required**
    - **now question is how best to achieve desired stiffness with minimum material**
- **FE model limited to just outer barrel, since European collaborators are now designing inner shells**

gravity sag, ~10.43µm





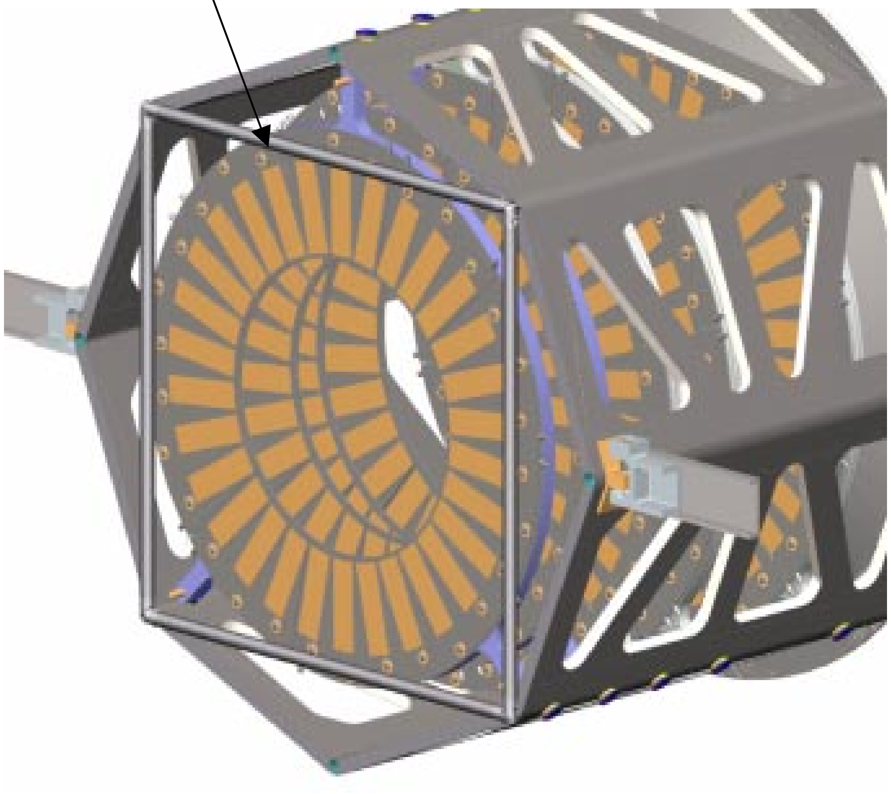
fundamental mode, 77.5 Hz

Frame Reinforcement

Concepts Under Study

- **Tubular end truss**
  - **Demountable**
  - **Does not block passage of services to any great extent**
  - **Tubes are 10mm OD with a 0.6mm wall, composite construction similar to longitudinal members**
- **Objective is to minimize frame compliance in the lateral direction**
  - **end reinforcement significant contributor to reducing compliance**

End reinforcement example



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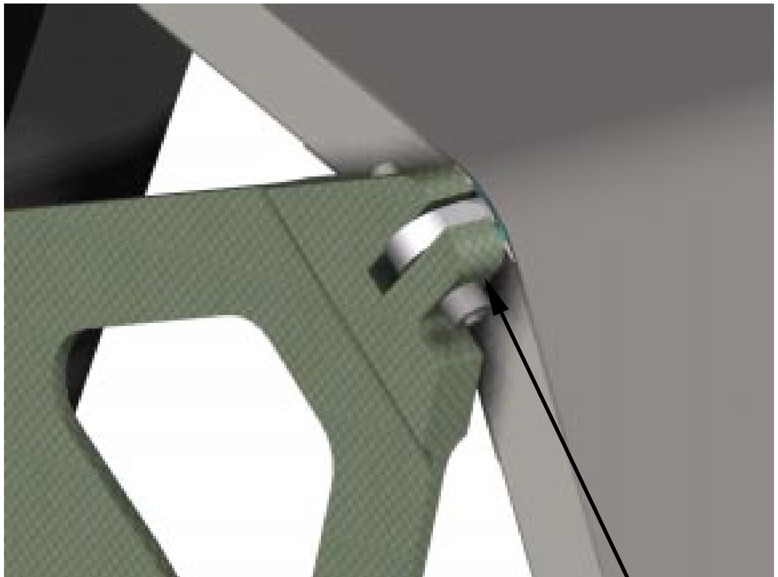
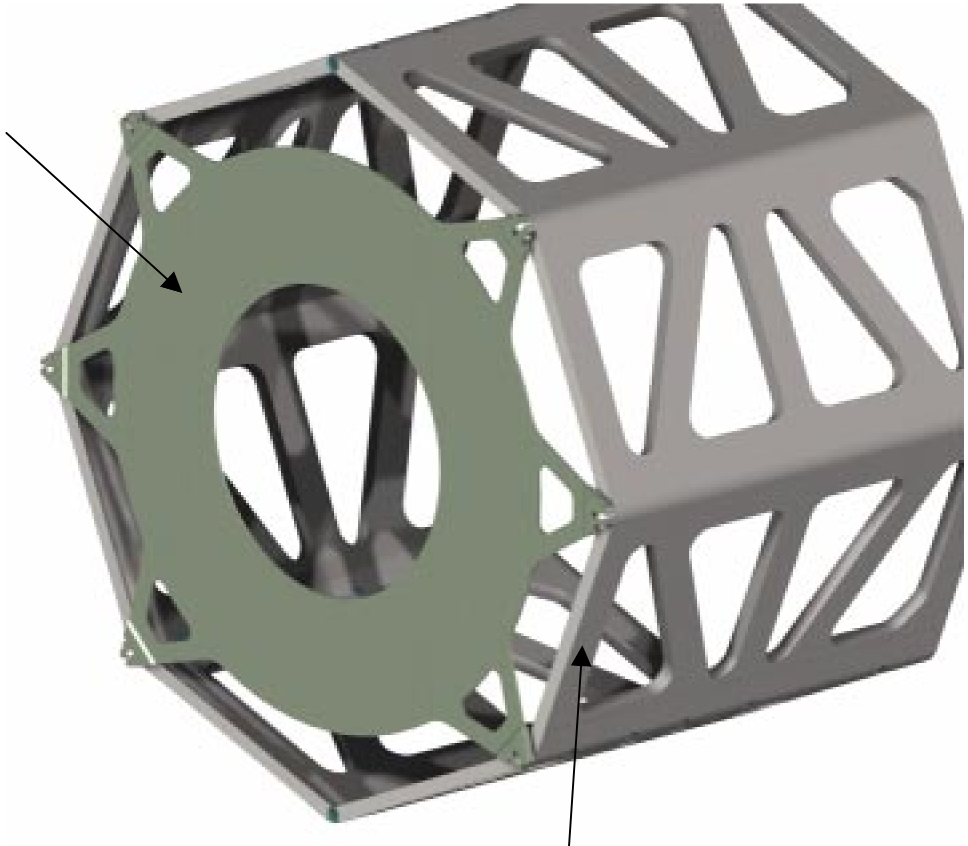
Frame Reinforcement

New Study Option-*provides protection for last disk*

Reinforcement replaces material at end of frame





Connection to frame corner (as before)

Goal is to remove material from end of frame

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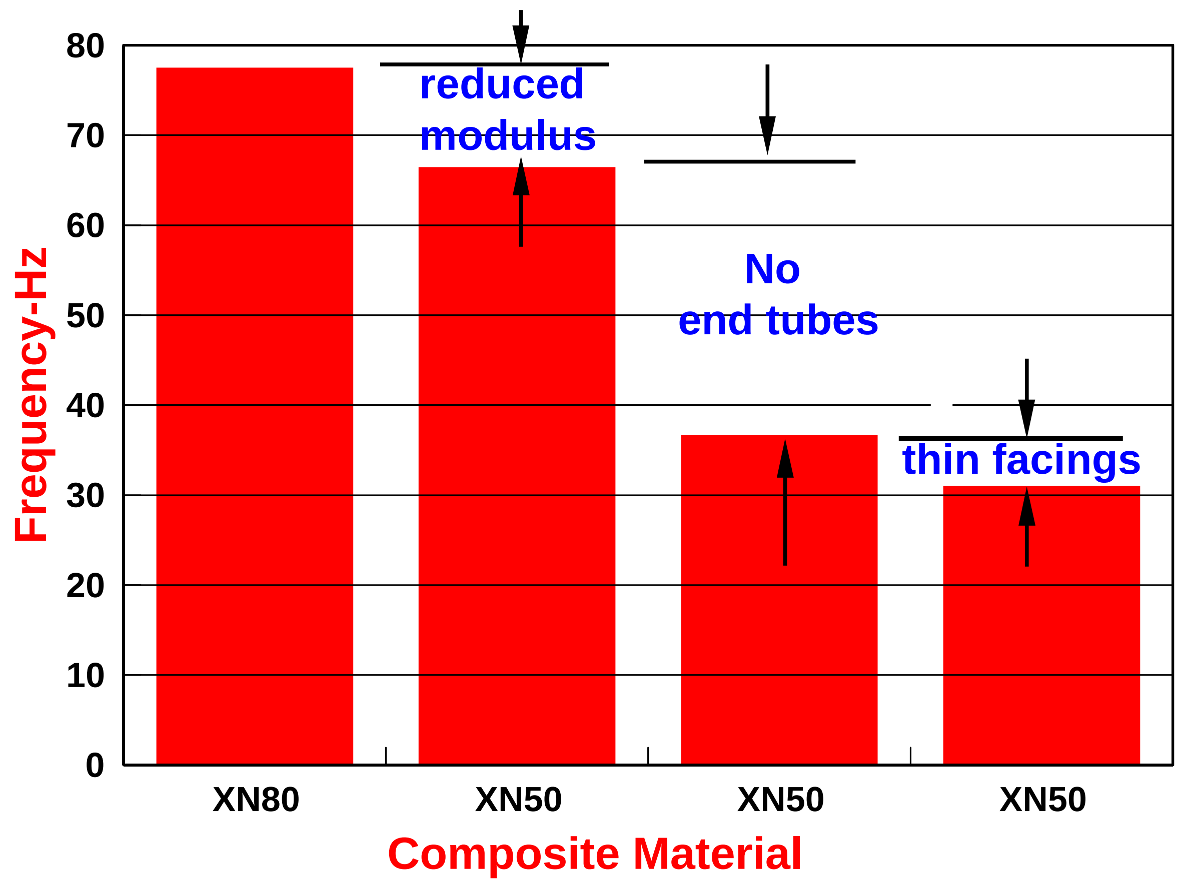
FEA Summary

Reduction In Dynamic Stiffness



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FEA Work Remaining

- **Issue remaining: *too much material***
  - **Radiation length of frame sections within budget <0.36%, except end sections, with material intercepted at shallow angle.**
- ***Material can be reduced by*:**
  - **End frame reinforcements**
    - **however, as yet, they increased material mass to undesirable level**
  - **Using higher modulus graphite fibers**
    - **High modulus fiber boosts stiffness 60%, no R_L penalty**
  - **Core material shear modulus above 55MPa**
    - **satisfied by high modulus honeycomb (*albeit expensive)***
- **New concepts to be studied using FEA**
    - **Relocate frame reinforcement entirely to end-keeping material at more normal incidence**

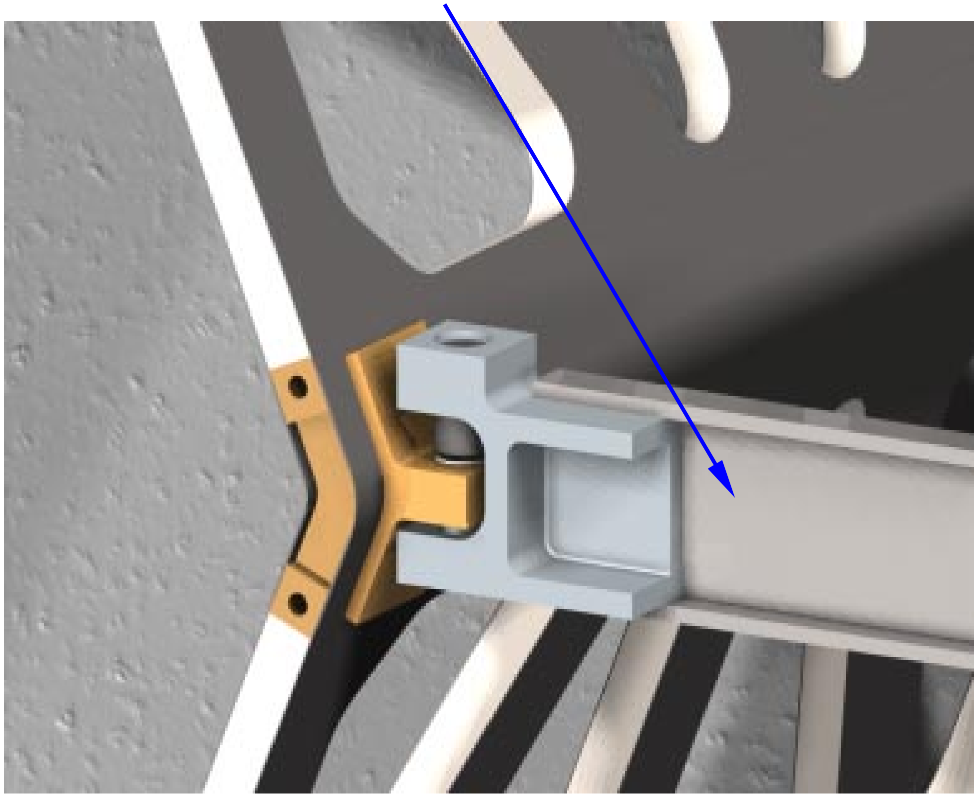
Side Issue

  - **Investigate low cost method of obtaining high modulus fiber systems**
  - **Evaluate prospect of achieving very low density, low cost carbon foams, thereby eliminating need for expensive honeycomb**

Mounting Concepts

- **Pixel/SCT mount design concept will be an important influence on the Global Supports design, *suppose:***
  - **kinematic to extent practical**
  - **Four point support**
    - **1 point XYZ**
    - **1 point XY**
    - **2 points Y**
  - **All support points are adjustable vertically**
  - **Pixel frame reinforced locally to resist lateral loads**

40mmX10mmX3mm
SCT mounting channel



Possible concept-*where detector is retained in the mounts*

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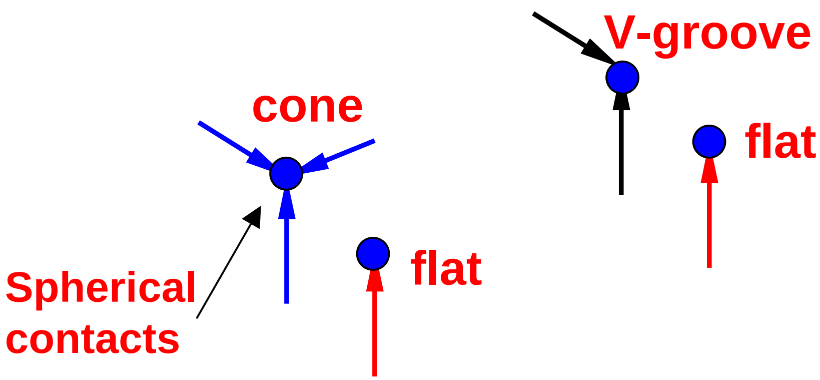
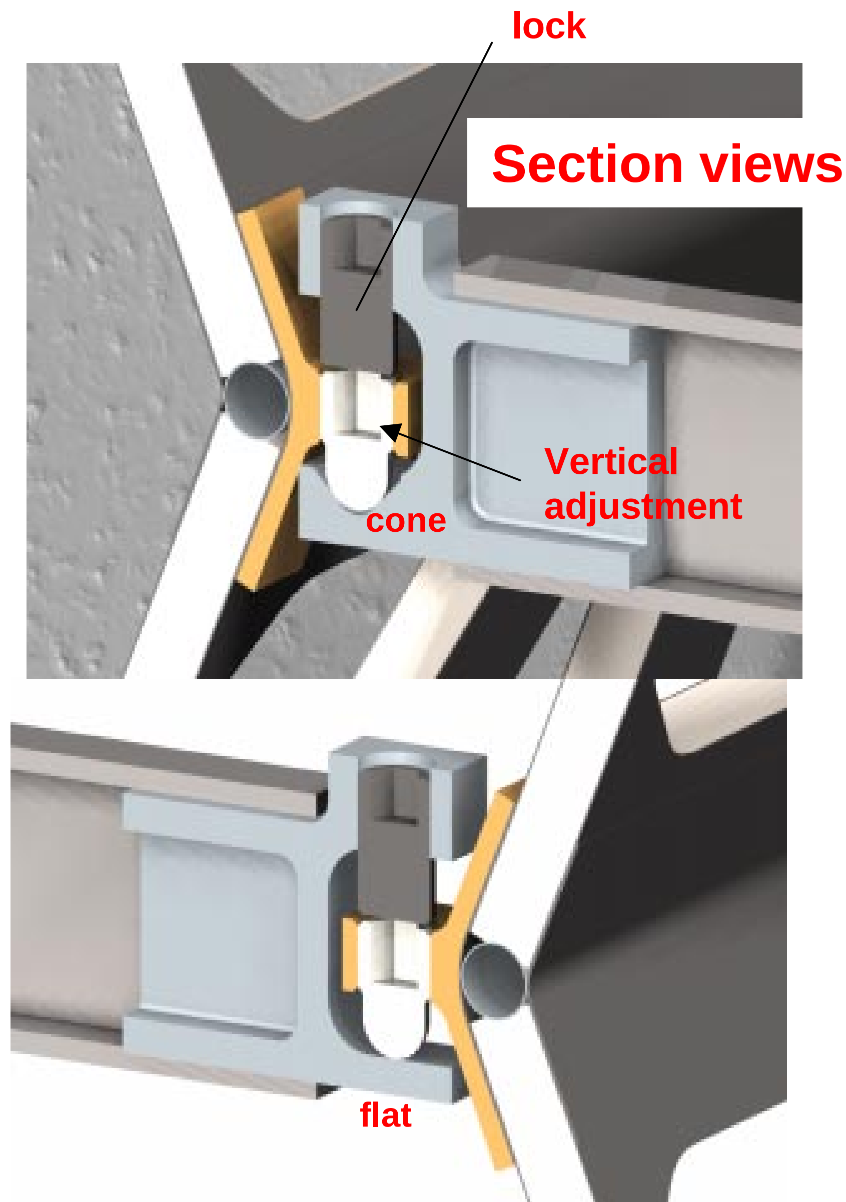
Mounting Concepts

- **Mount concept provides:**
  - Vertical adjustment for leveling detector at each corner

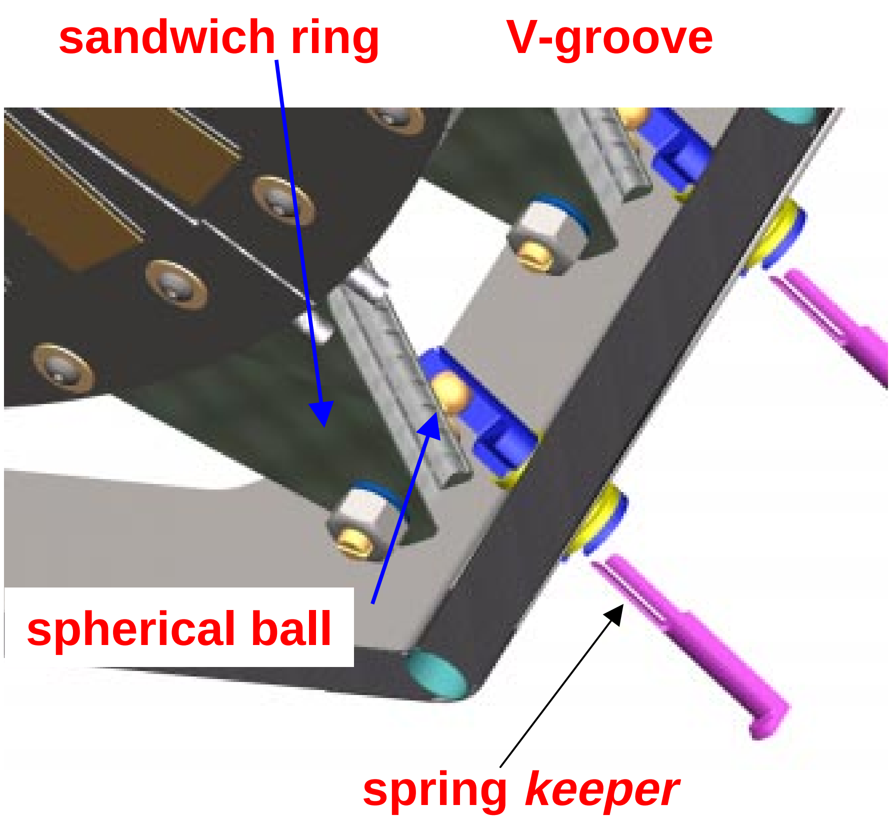


  - Conical seat and V-groove track at opposite end position detector laterally
  - decentration of detector from 40°C change is nominally 0.01 mm
    - propose offset built-in to negate this effect



Disk Mounting Concepts

- **Assembly sequence**
  - Disk assembly inserted into frame
  - Spherical balls on mounting ring are placed onto three V-grooves
  - Spring *keeper* inserted from outside to restrain spherical ball in V-groove
  - Spring keeper is guided by the machined bushing bonded in the frame structure and fixed in place on the outside of the frame
- **Considerations**
  - Required spring force to resist movement of disk from extraneous forces caused by services
  - Material selection



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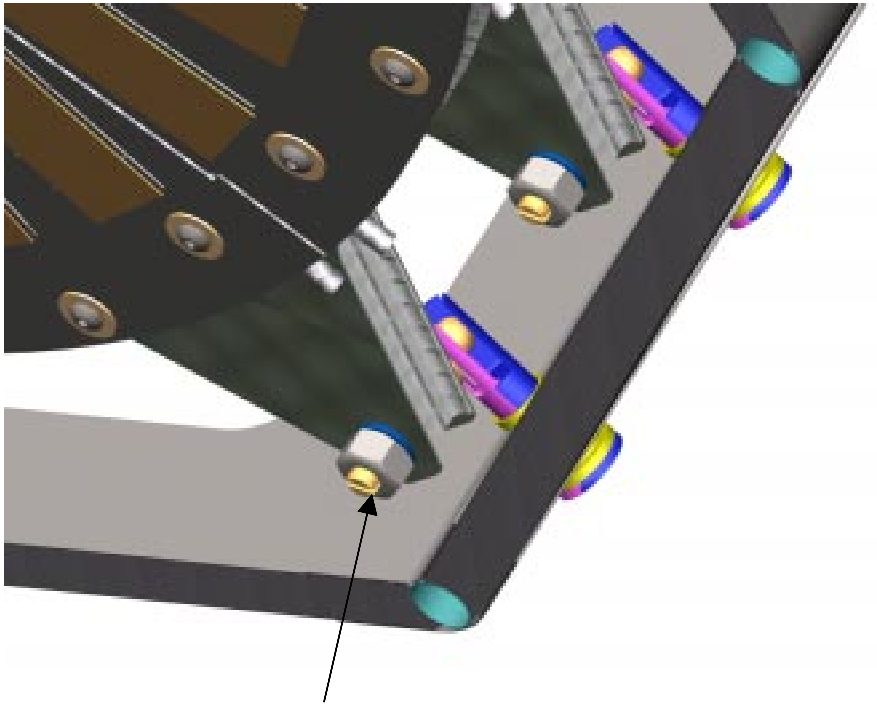
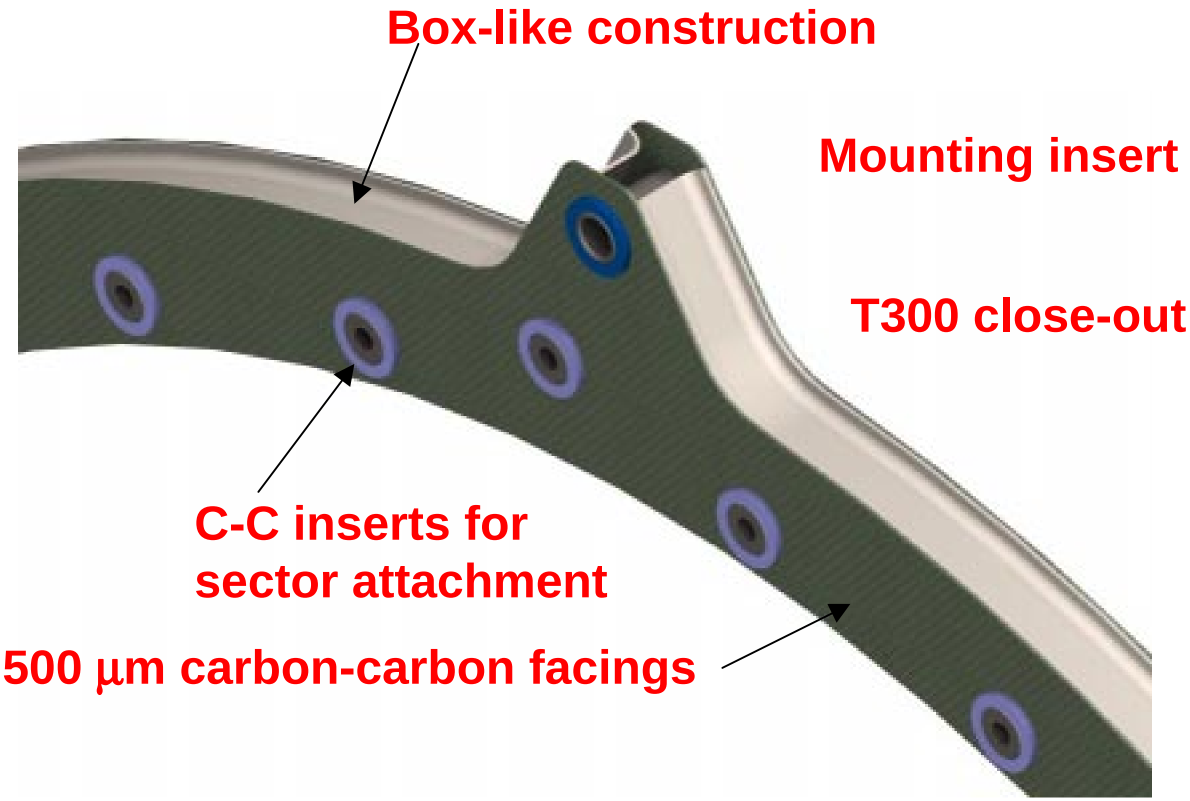
Disk Mounting Concepts

- **Adjustment features**
  - R-ϕ disk position is obtained by precise location of three point ball support in three V-grooves
  - Final positioning of disk provided by adjustment screw (fine thread)
  - Adjustment screw provides pure axial motion, as well as tip/tilt
- **Considerations**
  - Material selection of individual components needed
    - use composite materials to extent practical
    - to what extent metallic (Be) elements are useful is unclear at this time
  - Prototyping
    - Demonstrate zero backlash at component level



Disk Mounting Concepts

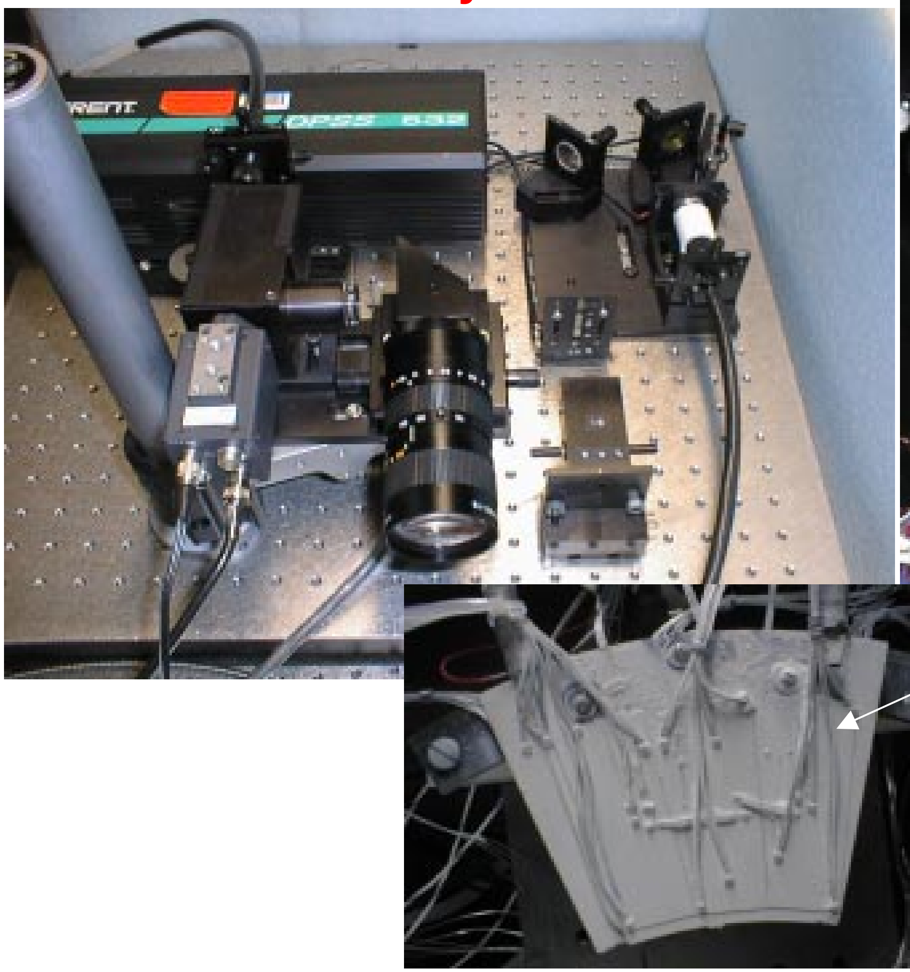
Sector mounting ring prototype for Disk Assembly



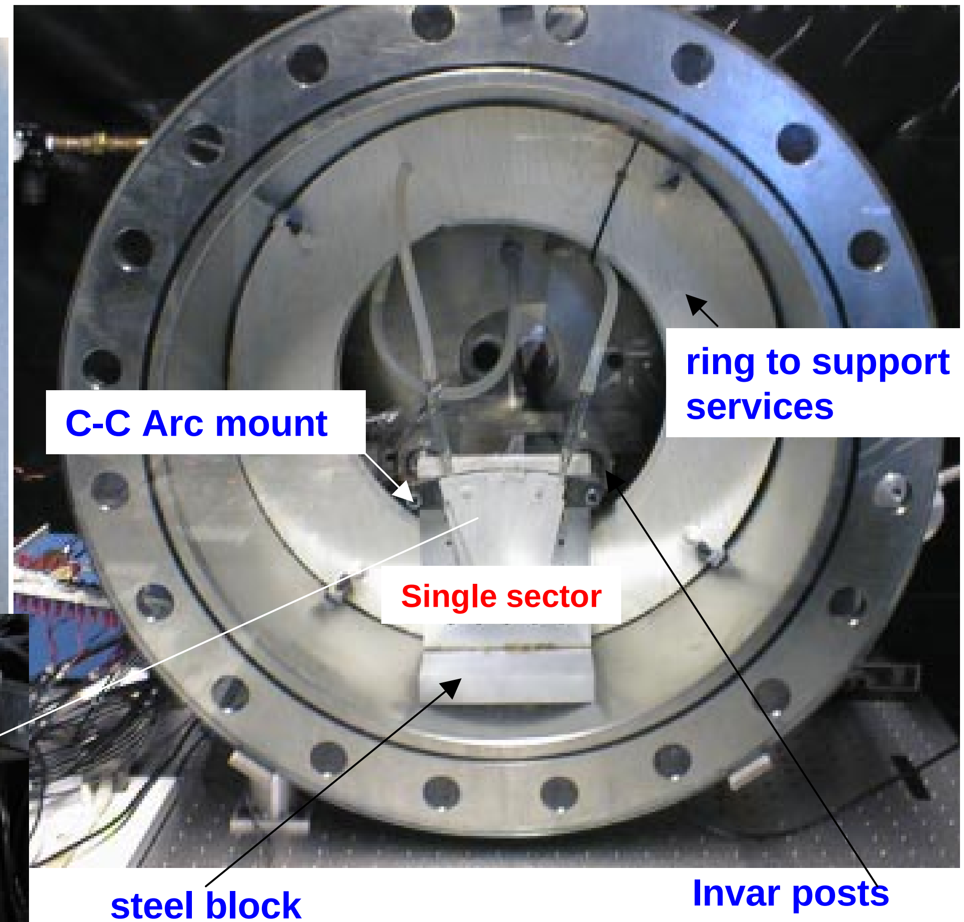
Stability Measuring Capability

Sub-micron Resolution Using TV Holography

Laser/CCD Camera/Fiber Optics Assembly



Test Facility for Full Disk



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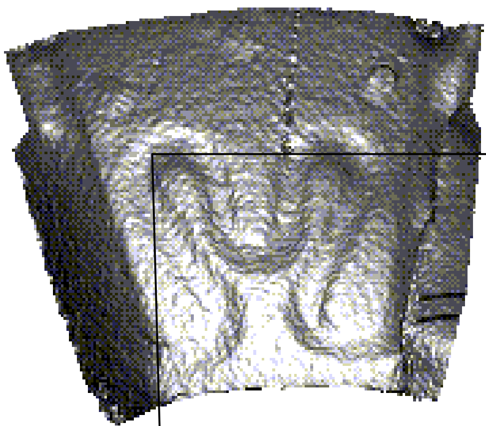
Examples of TVH Sensitivity

Sector without modules

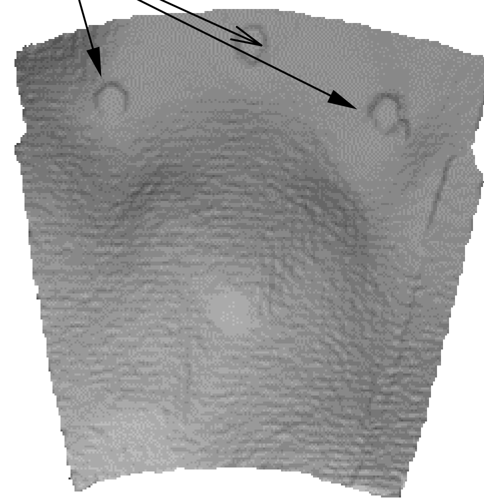
Sector with modules

Unwrapped phase maps



Depression, *print thru of coolant tubes*

Distortion after a 2.3 °C temperature change

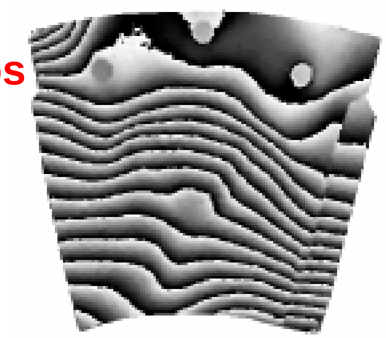


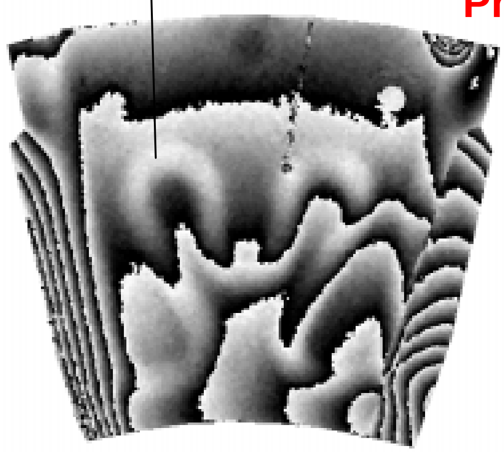
Support points

Front edge

Back edge

Phase maps



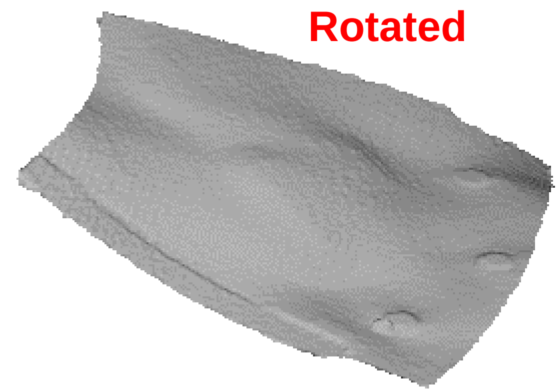


2.6 µm distortion

ΔT=-1.12°C @ T=21.67 °C

~4-5 µm's peak distortion

Rotated



W.O. Miller
U.S. ATLAS Internal Review March 1999

Near Term Objectives

- **Progress thus far:**
  - Established and analyzed frame concept
  - Have defined an approach for entire Global Support System
    - including rough cost of frame
  - Identified technical issues that need to be addressed
    - final choice in facing and core material
    - construction details in plane of SCT/Pixel mounting
  - Reviewed preliminary cost proposals from three vendors
  - Soliciting bid for prototype from low bidder on initial cost proposal
- **Near term objectives**
  - Continue FEA Studies
    - joint design
    - material selection
    - end reinforcement
  - Construct prototypes
    - sandwich specimens
    - full frame section

Prototype Milestones

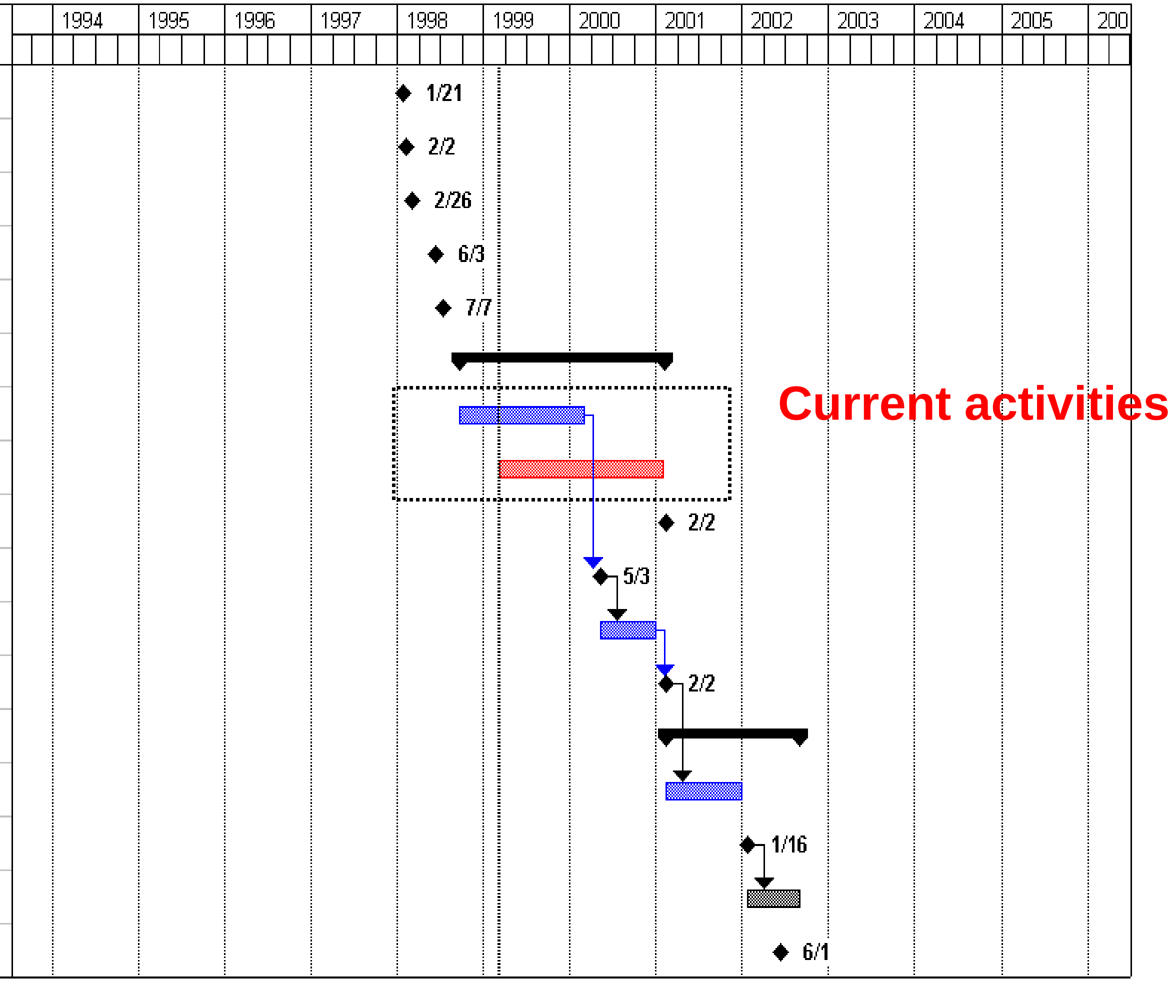
- Request Quote for Baseline Design Concept (11/15/98) √
- Review Vendor Cost Proposals and Vendor Survey (2/9/99) √
- Decision on Prototype Fab. Plan/Review with PDSG-(3/8/99) √
- Contract for End Section Prototype Phases (I,II, and III)------3/30/99
- Order Honeycomb Core Material (3/2/99) √
- Order Sandwich Facing Material------------------------------------3/15/99
- FEA of End Reinforcement (1st mode problem)-----------------3/30/99
- FEA of Corner Blocks---4/15/99
- 1st Sandwich Panel--5/30/99
- Evaluation of 1st panel Without/With Cutouts------------------6/15/99
- TVH With Large Viewing Check-out complete-------------------7/01/99
- Full Scale Prototype Complete--------------------------------------9/15/99
- Preliminary Stiffness Tests Complete-----------------------------10/15/99

U.S. ATLAS

Global Supports

Schedule

ID	Task Name
3	Global Supports Design Review
4	Structures TDR Design Input
5	Support Structures Status Report
6	Support Structures Status Report
7	Global Supports TDR Review
8	Global Support Structures Development
9	Detailed Conceptual Design
10	Structural Prototyping/Tests
11	Complete All Structure Prototype Tests
12	Global Supports CDR
13	Global Supports Preliminary Design
14	Global Supports PDR
15	Global Supports Construction
16	Final Design
17	Global Supports PRR
18	Support Structure Fabrication
19	Availability of Structures (Desired)



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