Two Pixel Configurations Under Study

- **First: *A Monolithic Integrated Structure***
  - Axial array of six per half structure
  - 21.4mm wide detectors, array of 12
  - 6 cooling passages, double pass
  - 800mm long structure

- **Second: *Staves with Supporting Shell***
  - Circumferential array of 14 staves
  - 16.2mm wide detector, 48 modules per stave
  - Overall length 778mm

Integrated Monolithic Structure

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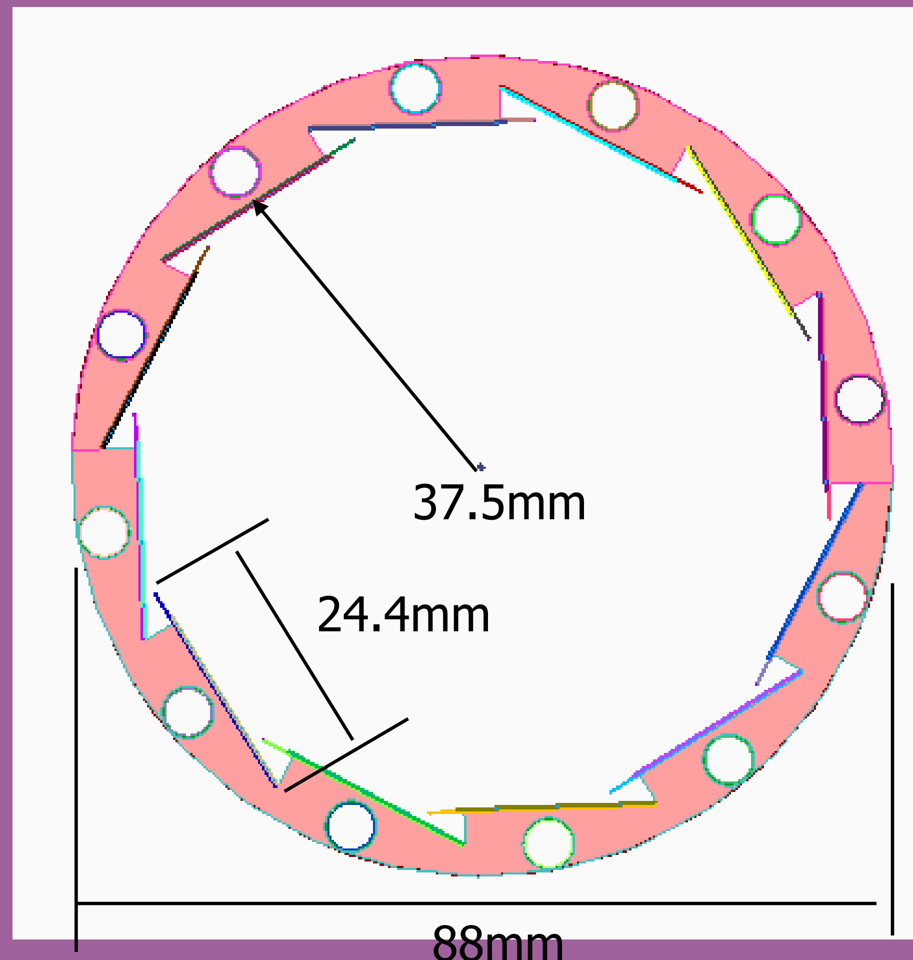
Preliminary Evaluation of Integrated Structure

- **Salient points**
  - **Constraint: stay clear zone around beam pipe**
    - **70mm diameter**
  - **Support split into two halves**
    - **Requires equal modules around perimeter; for grouping two cooling tubes, inlet and exit same end**
  - **Heat load assumption for 800mm length=120W**
    - **Two pass for each cooling tube: 5mm ID to limit pressure drop to <200mbar**
- **Issues under study: cooling and structural support for minimum radiation length**



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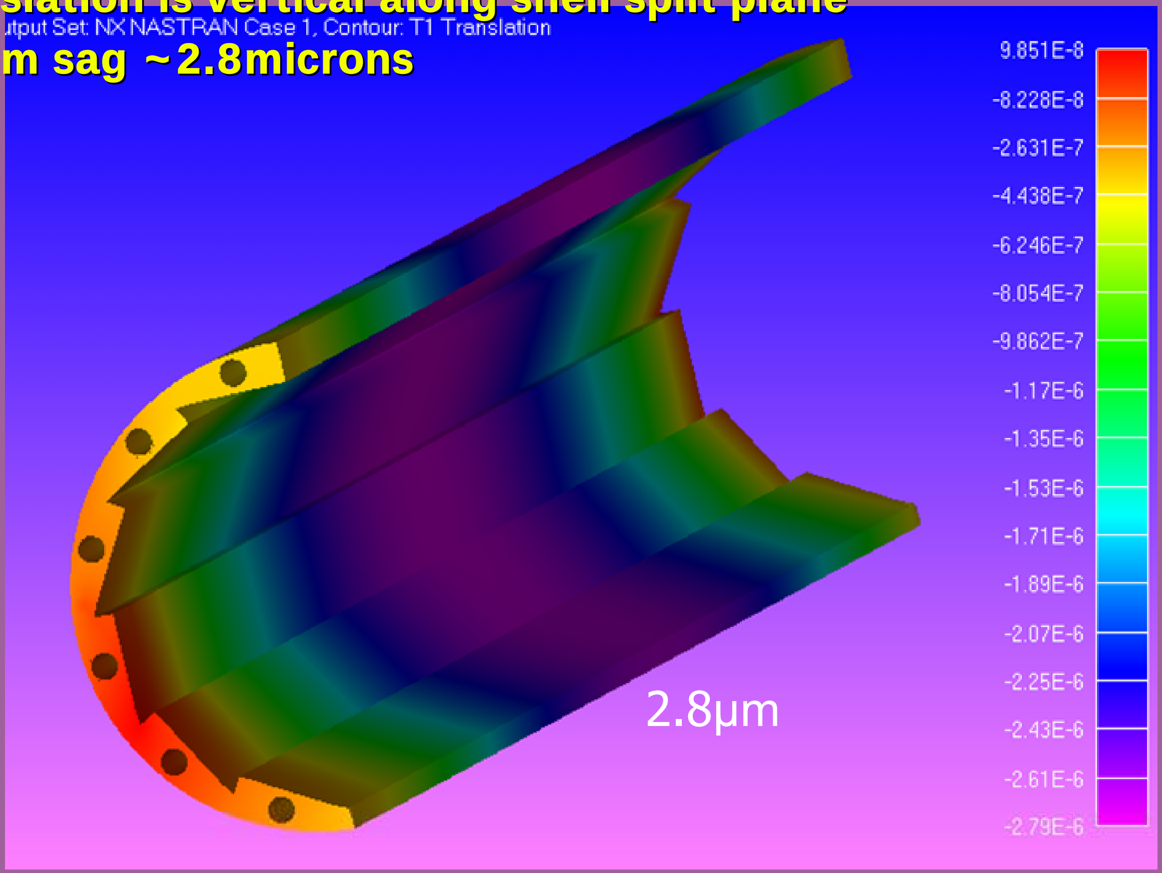
Integrated Structure (Continued)

- **Split Structure**
  - Sandwich structure, with cooling tubes embedded between 2-layer composite facing
    - Composite laminate produced using K13D2U fibers and Cyanate Ester resin
      - 5mils for two layers (0/90)
    - 5 mm ID Aluminum tubing, 12 mil wall (~5.6 mm OD)
- **FEA Structural Model**
  - Tubes and foam core treated as solid elements
    - Mass of coolant, average density 145kg/m^3
  - Outer surface laminate: used laminate element, with single material
  - Inner surface (saw-tooth) contain laminate elements with material designations for:
    - Composite layers (0/90)
    - Silicon module assembly, 0.5mm silicon
    - Cable, 0.9mm uniform along length

Gravity Sag

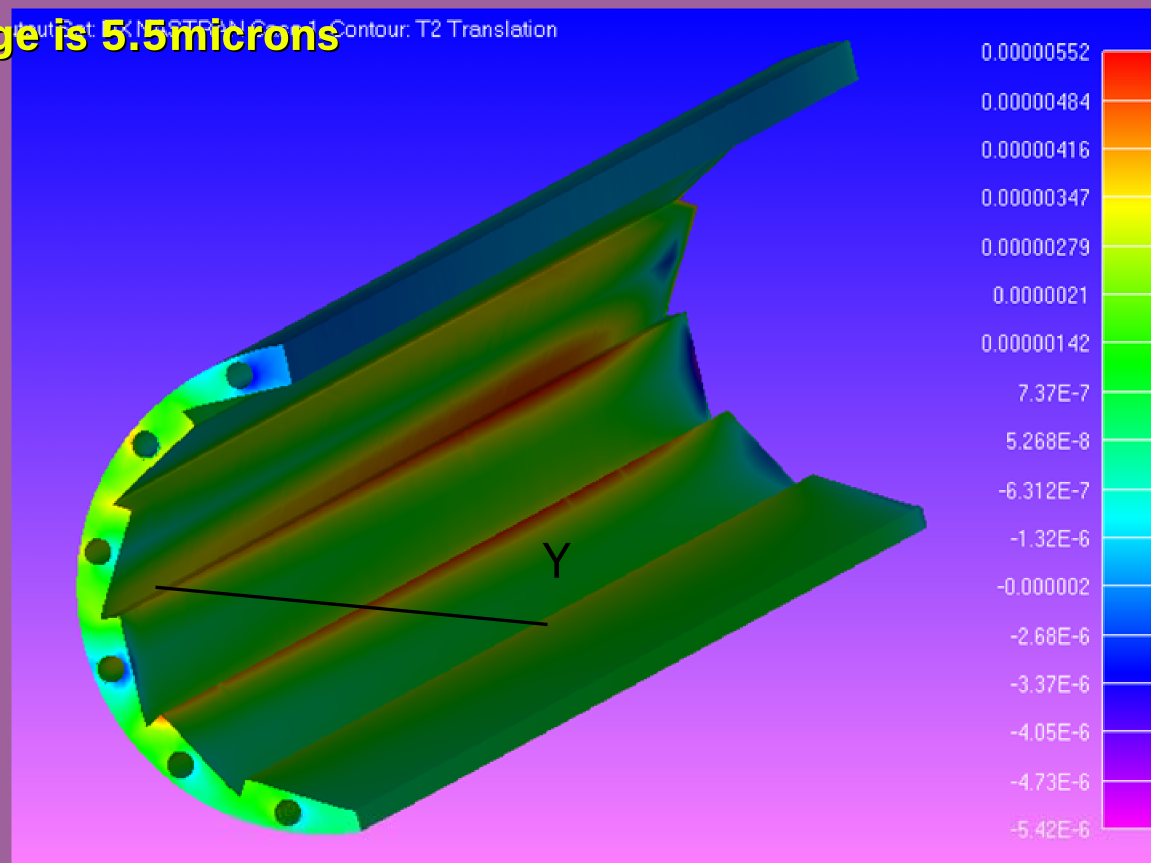
- **Model based on 1G loading vertical**
  - **Sag measured in local coordinates**
  - **T1: translation is vertical along shell split plane**
  - **Maximum sag ~2.8microns**



Thermal: 50C Temperature Change

- **Thermal strain due to cool-down**
  - **Local coordinates, T2 is transverse to vertical plane of symmetry**
    - **peak shape change is 5.5microns**

Unfortunately the out-plane distortion is a combination of T1 an T2



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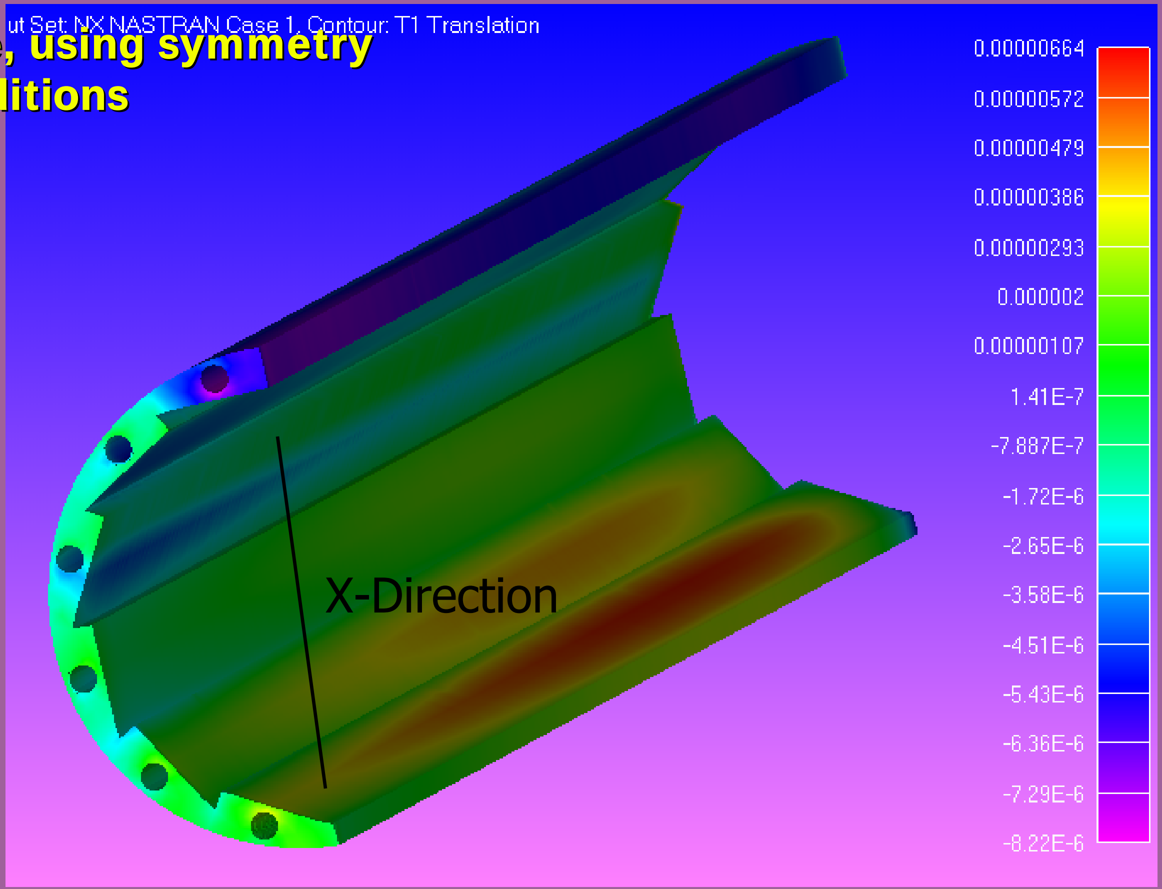
Thermal: 50C Temperature Change

- Thermal strain due to cool-down
  - X: direction 8.2 to 6.6 microns
    - X is split plane, using symmetry boundary conditions



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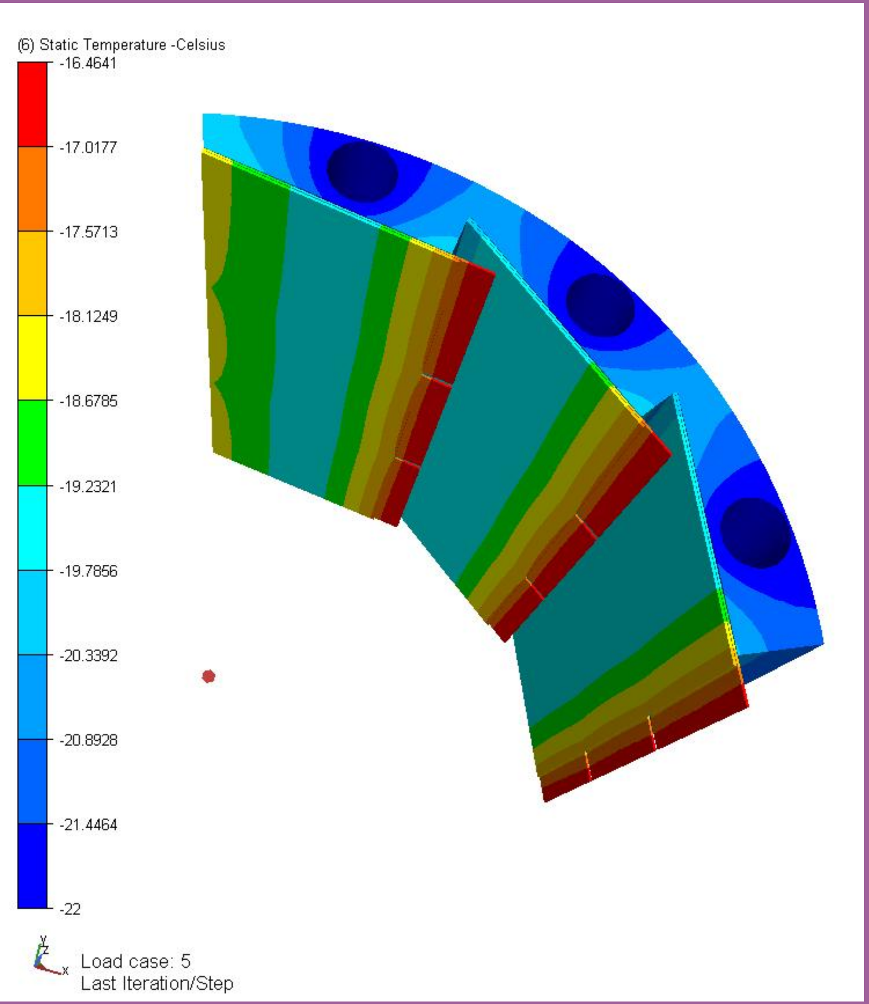
Pixel Thermal Solution- Integrated Structure

- **Description**
  - Isotropic carbon foam: 50W/mK
    - Specialized low density (0.14g/cc) foam: enhanced to high conductivity
  - Detector 250microns
  - Chips 200 microns
  - Bump bonds 25microns
  - Interface resistance from bonding chip to foam equal to 0.8W/mK; 4mil thickness (CGL7018)
  - Pixel chip heating: 0.6W/cm^2
  - Simulated tube wall -22ºC
- **Results**
  - Peak chip edge =-16.5 ºC
  - Detector lower than -17.5 ºC



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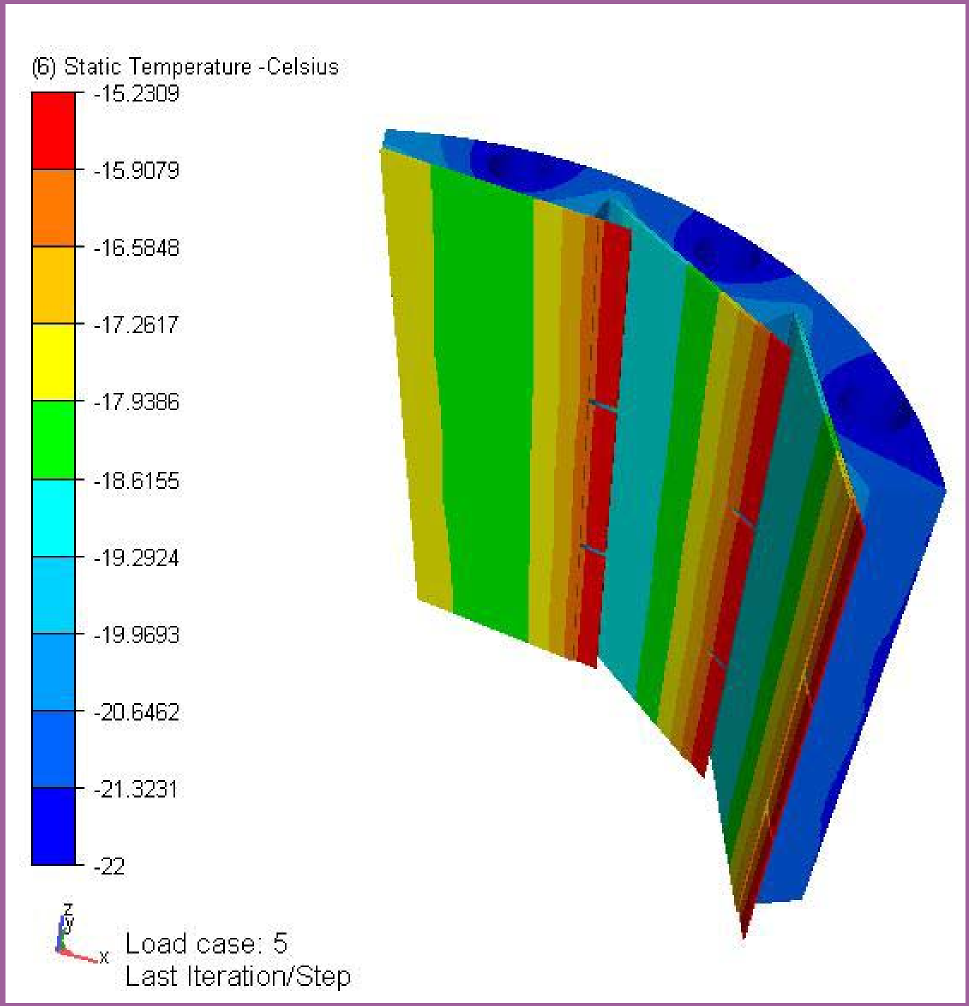
Pixel Structure (Cont.)-Composite Interface

- **Addition of Laminate**
  - Determine effect of adding composite laminate beneath electronics
  - 5mil Laminate thickness, plus 4 mil CGL 7018 adhesive beneath the electronic chips
    - Laminate K=1.44W/mK
- **Result of Laminate Addition**
  - Detector peak -16.3ºC versus -17.5ºC before
- **Detector temperature**
  - Closely matches local chip temperature by virtue of bump bonds



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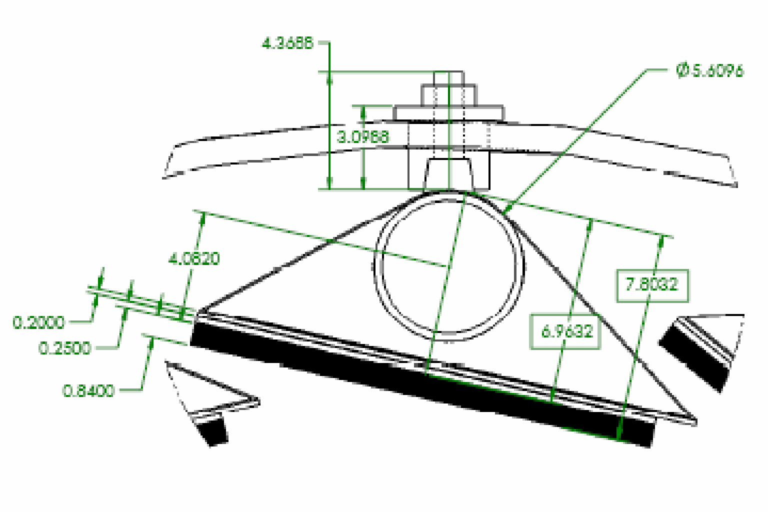
Stave Approach

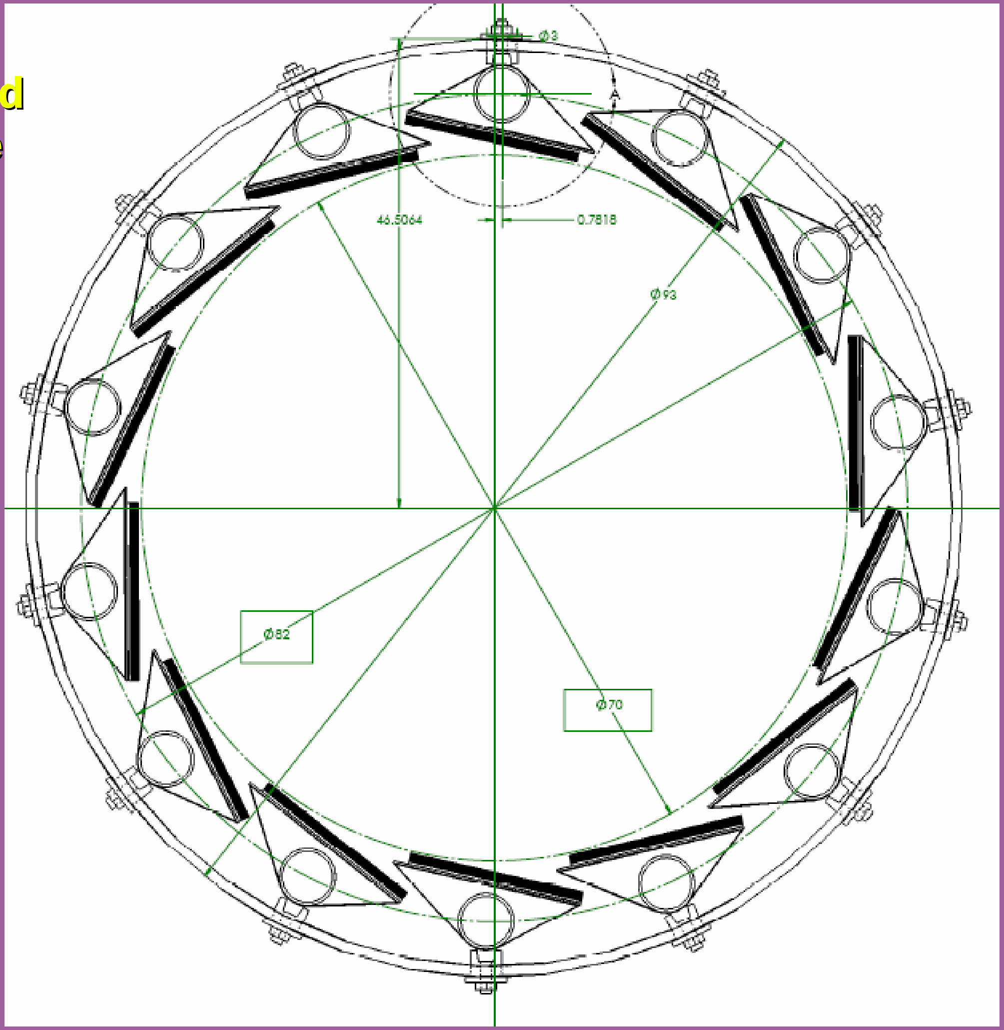
Staves With Support Shell

- **Issues**
  - Confined space, need additional room for support shell
  - Provide stave with 5 point support
    - Minimize sag and out-of-plane distortion from sub-cooling
  - Minimize amount of construction material
    - Combination of high conductivity foam as before in the integrated design
      - And two layer laminate, uni-tape or single layer of woven cloth
    - What happens to interfacial stresses
      - Calculated, but best resolved through testing
- **Approach thus far**
  - Design layout to compress geometry: inner diameter set at 70mm, outer diameter ? (most likely ~88mm)
  - Analyze basic stave stiffness and thermal performance

Initial Layout-Stave 1

- **Concept**
  - Retained features of integrated design, same cooling tube size
  - Less foam, but added cylinder
  - Outer diameter ~93mm
  - Inner diameter 70mm





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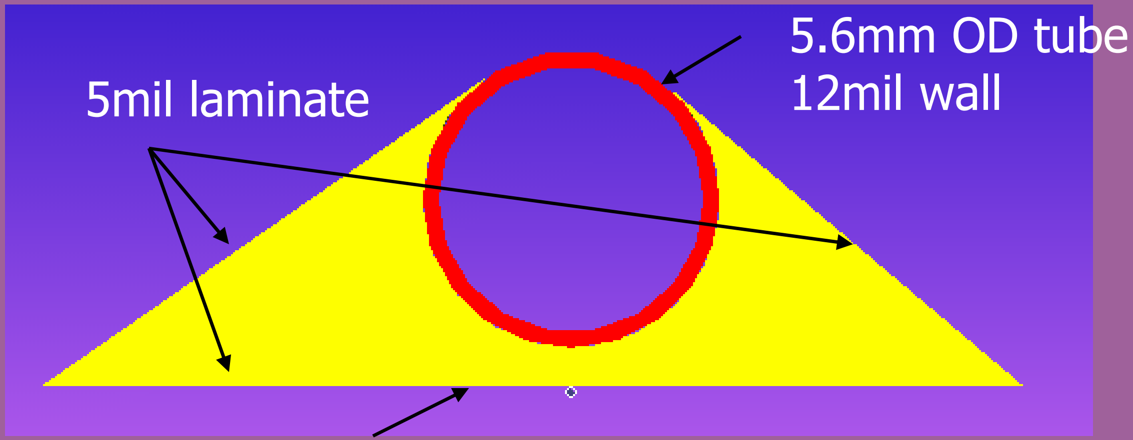
Stave 1: Basic FEA Configuration

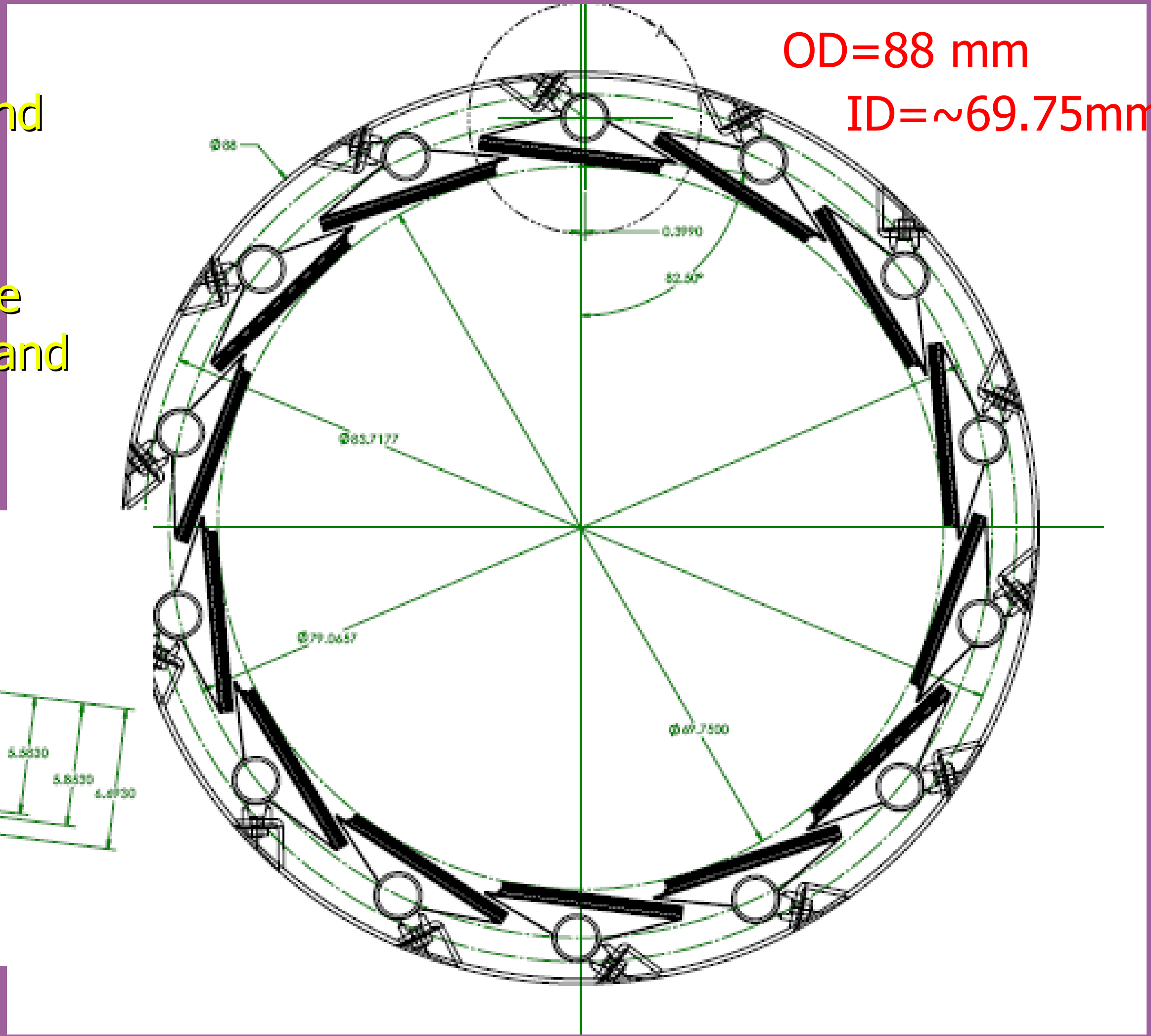
- **Effects simulated**
  - **Mass of coolant, average density 145kg/m^3**
  - **Laminate, 2 layers 2.5mil, 0/90, K13D2U**
- **Radiation Length estimate=0.532%**
  - **Foam=0.11%**
  - **Tube=0.3%**
  - **Composite=0.11%**
  - **Coolant=0.012%**

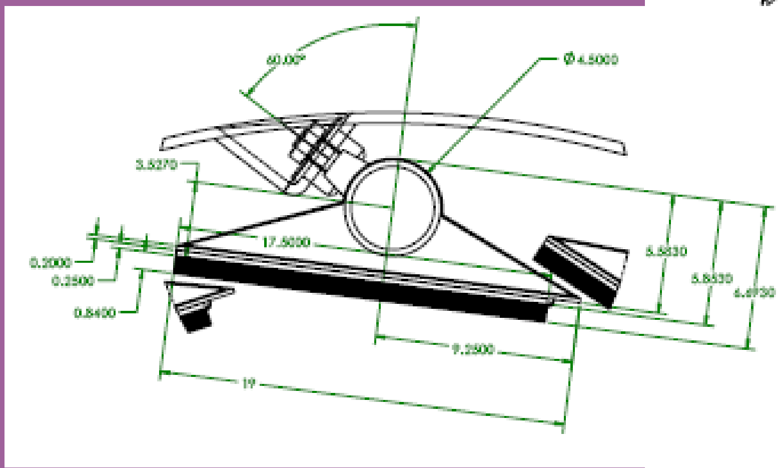


0.5mm of silicon to simulate chips and detector
Also 0.9 mm of Kapton cable for additional mass

Second Configuration-Stave 2

- **Goals**
  - Reduce tube size and amount of foam material
  - Analytically evaluate impact on thermal and mechanical design





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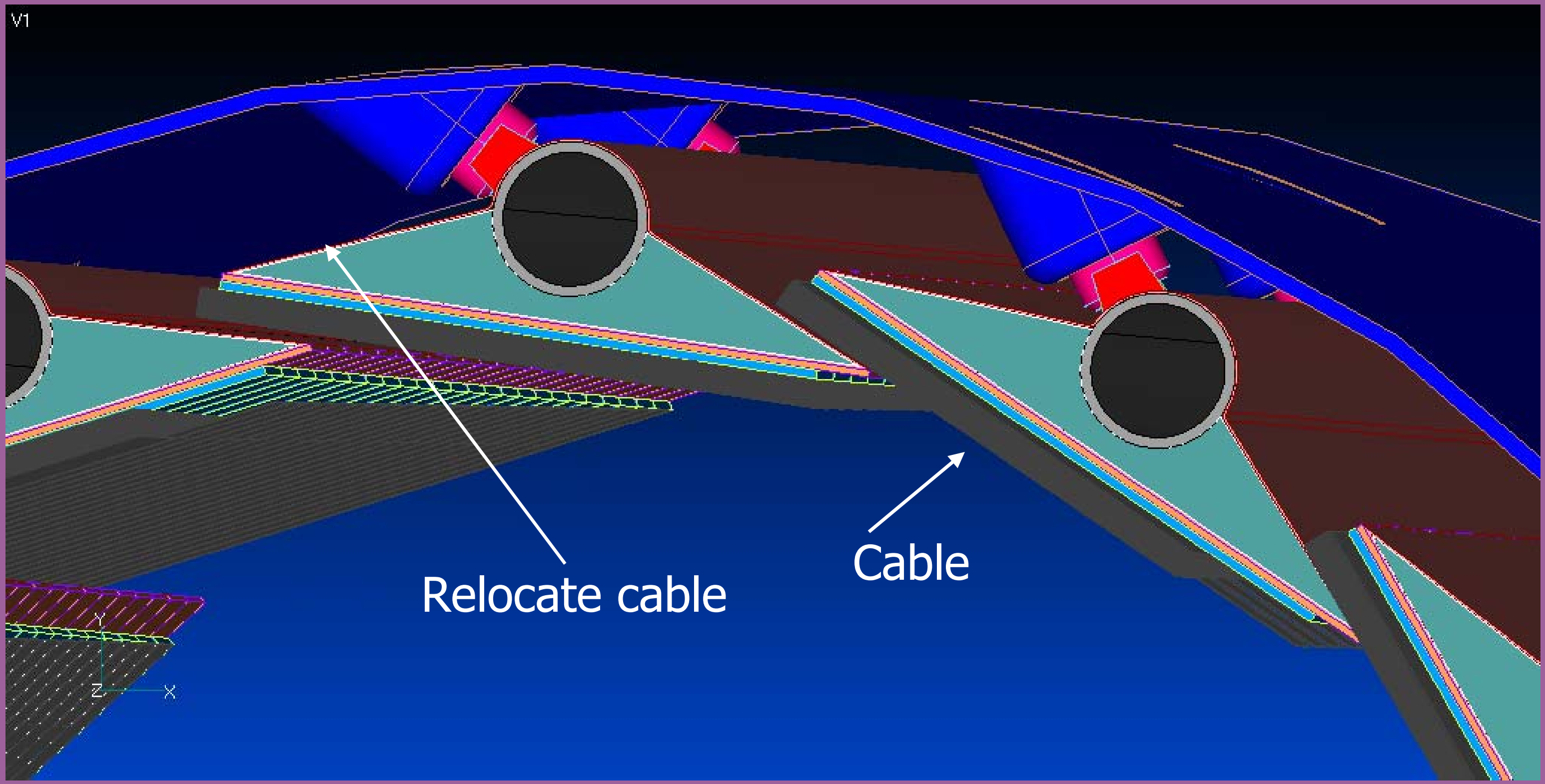
Stave 2: With Offset Mounts

- **Space on back-side next to mounts appears adequate to place cable, for wrap-around mounting**



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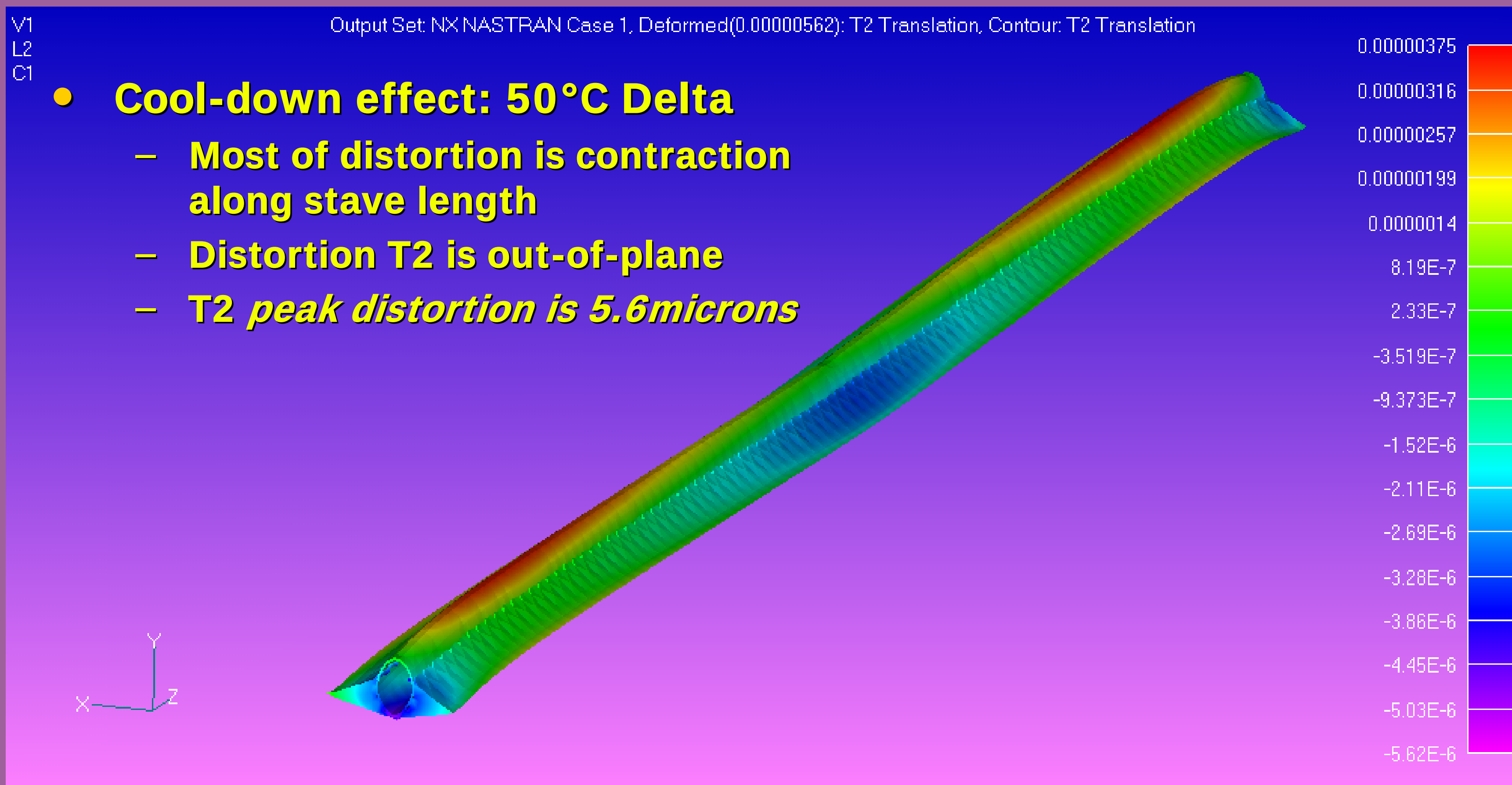
Stave 1: Gravity Sag

- **Upper Stave position near vertical centerline**
  - **Modeled ½ length, *from mid plane of symmetry of a 778 mm long stave***
  - **Model provides effect of a 5 point support stave length**
- **Resulting gravity sag *0.085microns***

Stave 1: Thermal Distortion

- **Cool-down effect: 50°C Delta**
  - **Most of distortion is contraction along stave length**
  - **Distortion T2 is out-of-plane**
  - **T2 *peak distortion is 5.6microns***



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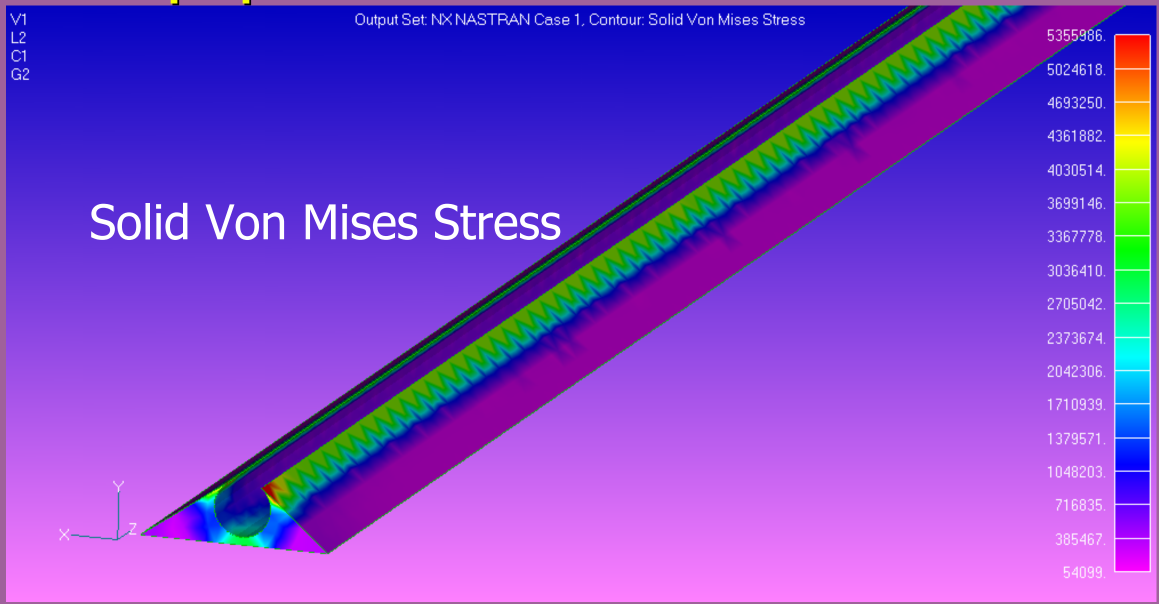
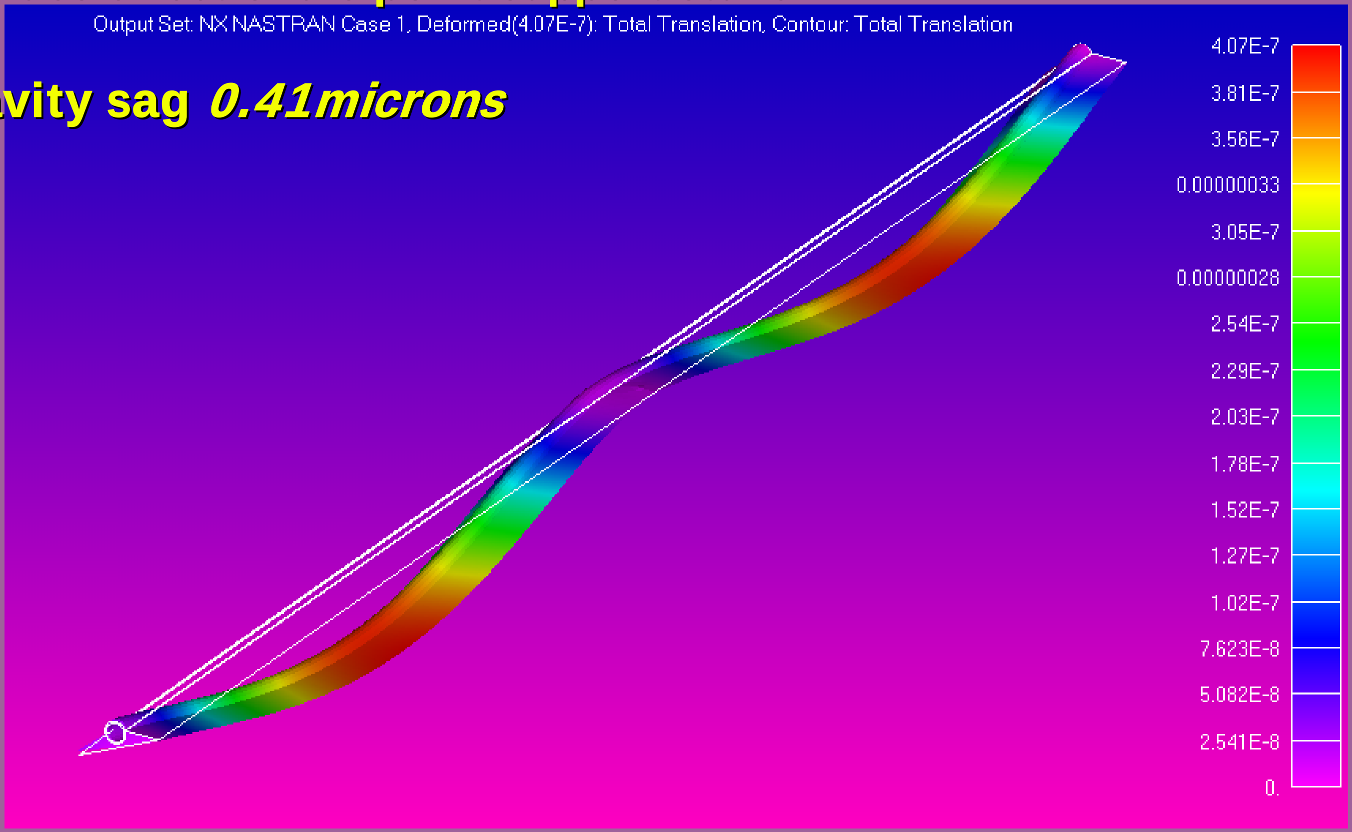
Stave 1: Thermal Strain

- **Stress in Foam/Tube Interface**
  - **Evaluated without compliance of bonding adhesive (CGL7018 type)**
  - **Contraction of Al tube produces local stress of 300psi at interface**
    - **Effect best evaluated through testing**
  - **Plan is to use special Reticulated Vitreous Carbon Foam with enhanced thermal and mechanical properties**



Stave 2: Gravity Sag

- **Upper Stave position near vertical centerline**
  - **Modeled ½ length, _from mid plane of symmetry of a 778 mm long stave_**
  - **Model provides effect of a 5 point support stave length**
- **Resulting gravity sag _0.41microns_**



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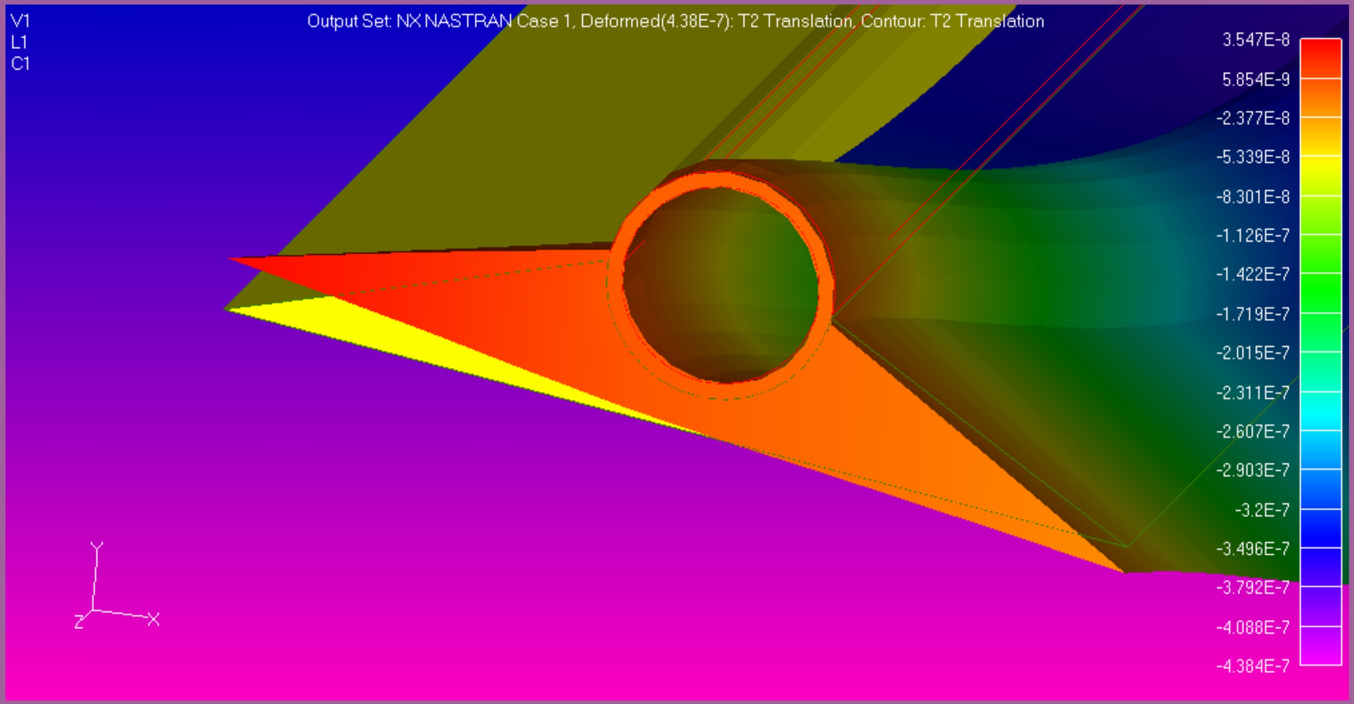
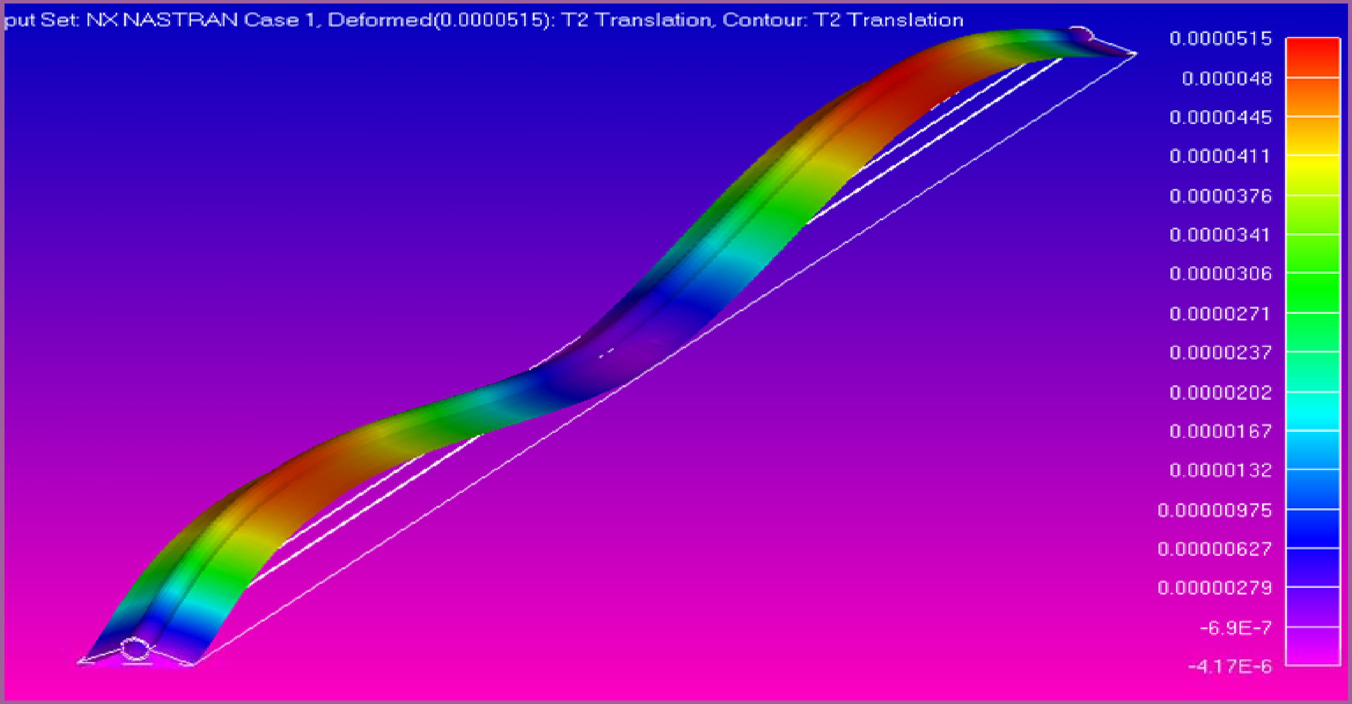
Stave 2: Gravity Sag-Off Set Mount

- **Effect on rotation of stave**
  - **Maximum rotation 1.9μradians due to sag**



Stave 2: Thermal Distortion

- **Stave with out-of-plane bending due to cool-down 50°C**
  - **Modeled ½ length, *from mid plane of symmetry of a 778 mm long stave***
  - **Model provides effect of a 5 point support stave length**
- **Resulting bending *51.5 microns***



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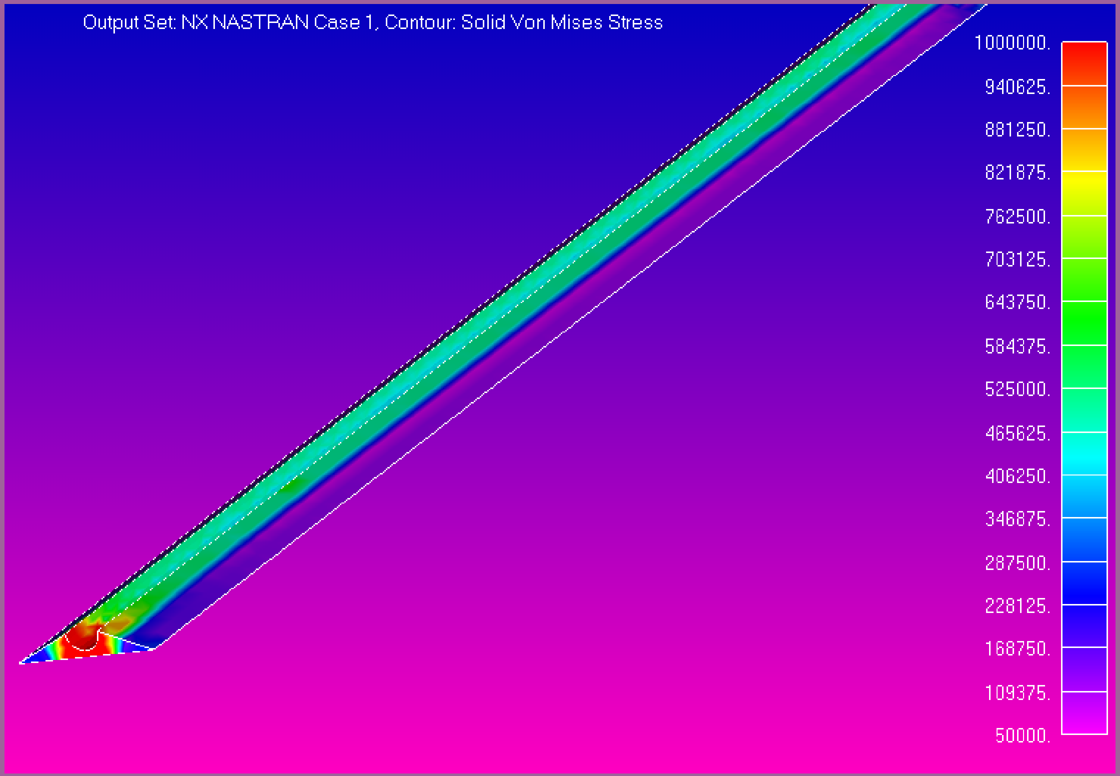
Stave 2: Thermal Strain

- **Stress induced by contraction**
  - **Less than in Stave 1 geometry**
  - **145psi, more localized at ends**
  - **Be mindful that compliance of adhesive not present**



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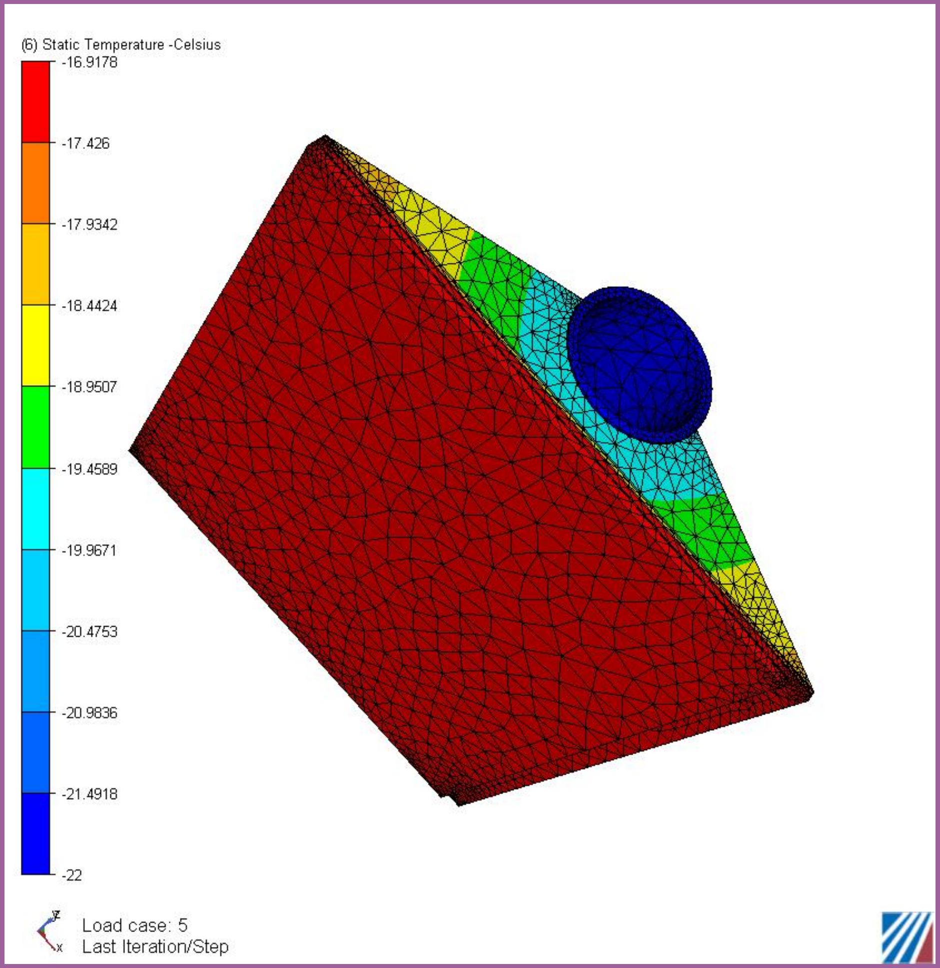
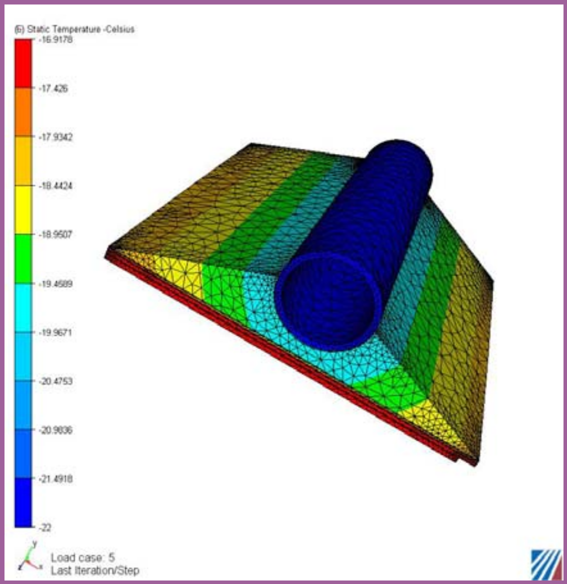
Stave 2: Thermal Solution

- **Model Parameters**
  - Carbon Foam, 45W/mK
  - Composite Facing, K13D2U-55% vol fraction
    - 0/90, K_t=0.55W/mk, 220W/mK planar (no axial thermal gradient so this parameter is not an issue)
  - Chip 0.2mm
  - Bump bond thickness, .05mm
  - Detector, 0.25mm
- **Adhesives**
  - Tube to foam, 4mils, 0.8W/mK
  - Foam to composite facing, 2mils, 0.8W/mK
  - Chip to composite facing, 1mil, 0.8W/mK
  - Cable to detector module, 2mils, 1.55 W/mK

Stave 2: Thermal Solution-No Cable

- **Coolant Tube "BC"**
  - -22ºC
- **Chip Heat Flux, 0.6W/cm²**
- **Detector Temperatures**
  - Left edge, -16.9ºC
  - Middle, -17.3ºC
  - Right, -17.1ºC





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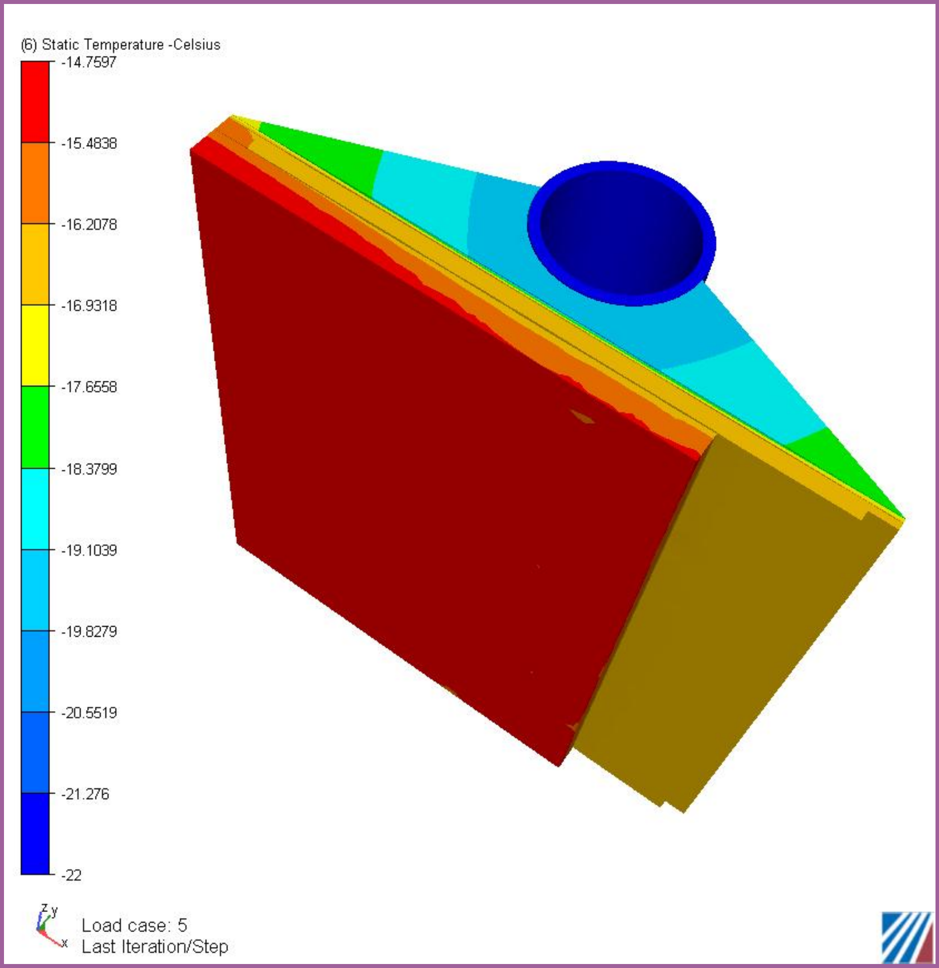
Stave 2: Thermal Solution-With Cable

- **Cable heat load**
  - Adds a heat flux of $0.1W/cm^2$ to the $0.6W/cm^2$ chip heat load
  - Gradient before was 4.7ºC, detector middle to tube inner surface
  - Would expect gradient of 5.48ºC now
  - Gradient *now* from detector middle to tube surface is 5.3ºC
- **Cable surface**
  - Peak -14.8ºC, or a ΔT=7.2ºC
  - Peak affected by K assumed for the copper/Kapton cable
    - Used 0.35W/mK, whereas Kapton alone is 0.12



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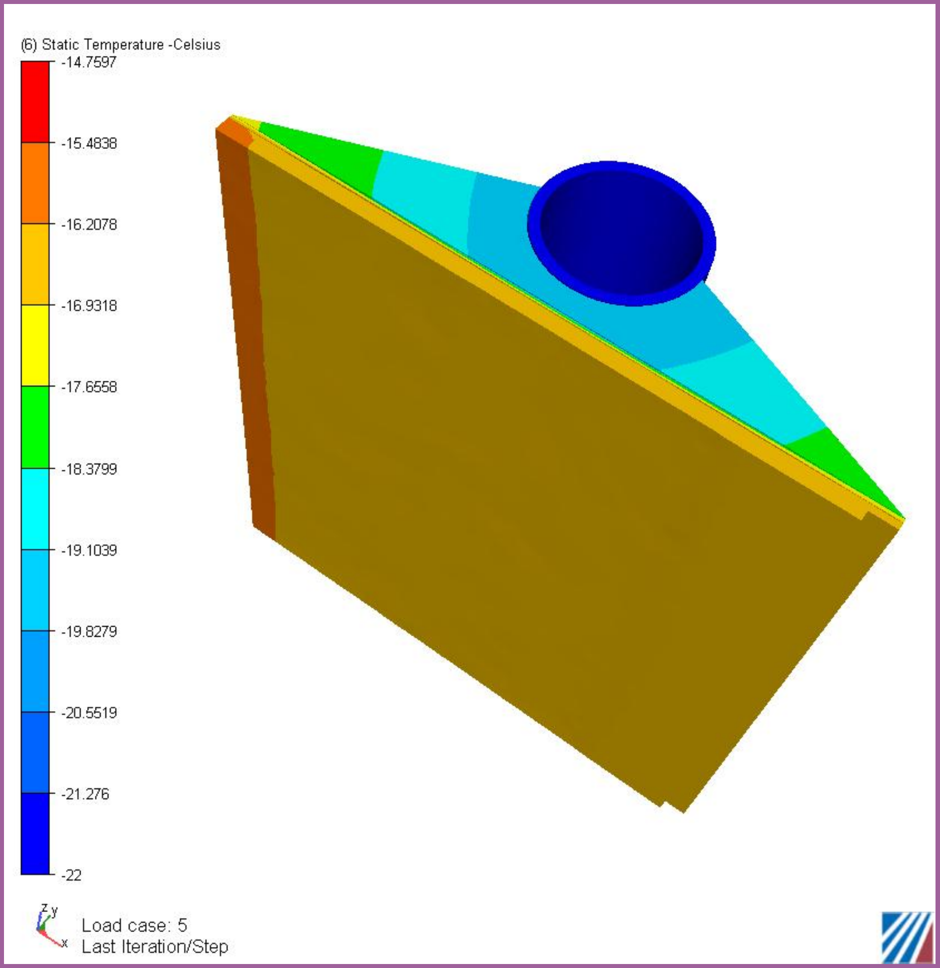
Stave 2: Thermal Solution-With Cable

- **Thermal plot with cable removed**
  - Illustrates uniformity in detector temperature



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Detector Temperature Summary

- **Thermal Solutions for two designs, but unfortunately different detector layouts**
  - Integrated, *different by chip over-hang*
  - Stave-like, *provides complete coverage*
    - *Two different foam/sandwich structures, one with less material analyzed first*
- **With time will bring configurations into consistency**
- **However, the predicted detector surface temperature for each is:**
  - Low-mass stave without cable heat load, -17ºC
  - Low-mass stave with cable heat load, -16ºC
  - Integrated Foam/Tube Support without cable load, -17.5ºC
    - Caution, as analysis proceeded slightly more conservative properties were used for the composite facing and the foam:
      - Facing 0.55W/mK versus 1.44W/mK
      - Foam 45W/mK versus 50W/mK