CMS Pixel Mechanical
FPIX Half Disk Design Updates

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10/28/2009

FPIX Half Disk Layout Requirements

1. *Fits within Phase 1 FPIX envelope definition*
2. *Modules oriented radially (requires only 2x8 modules, and slightly improves resolution compared to the layout of the current detector)*
3. *Locates all outer radius sensors as far forward and out in radius as possible (to minimize the gap in 4-hit coverage between the end of the 4th-barrel layer and the forward-most disk)*
4. *Maximize 4-hit coverage between end of 4th layer barrel up to eta = 2.5, for particles originating at the IP +/-5cm, using a minimum number of modules*
5. Keep the same 20 degree tilt as the current detector
6. Individual modules and/or module-support substrates to be removable and replaceable without disassembling other modules on the disks
7. Identical substrates (blades are the same)
8. Minimizes the amount of material required for cooling and module support (assuming cooling using CO_2)
9. Delta T < 5C across a single module (Highly desirable)
10. Separate inner from outer ring assembly for easier replacement of blades on the inner ring (with earlier radiation damaged modules). (Desirable)

FPix Phase 1 Upgrade Plans

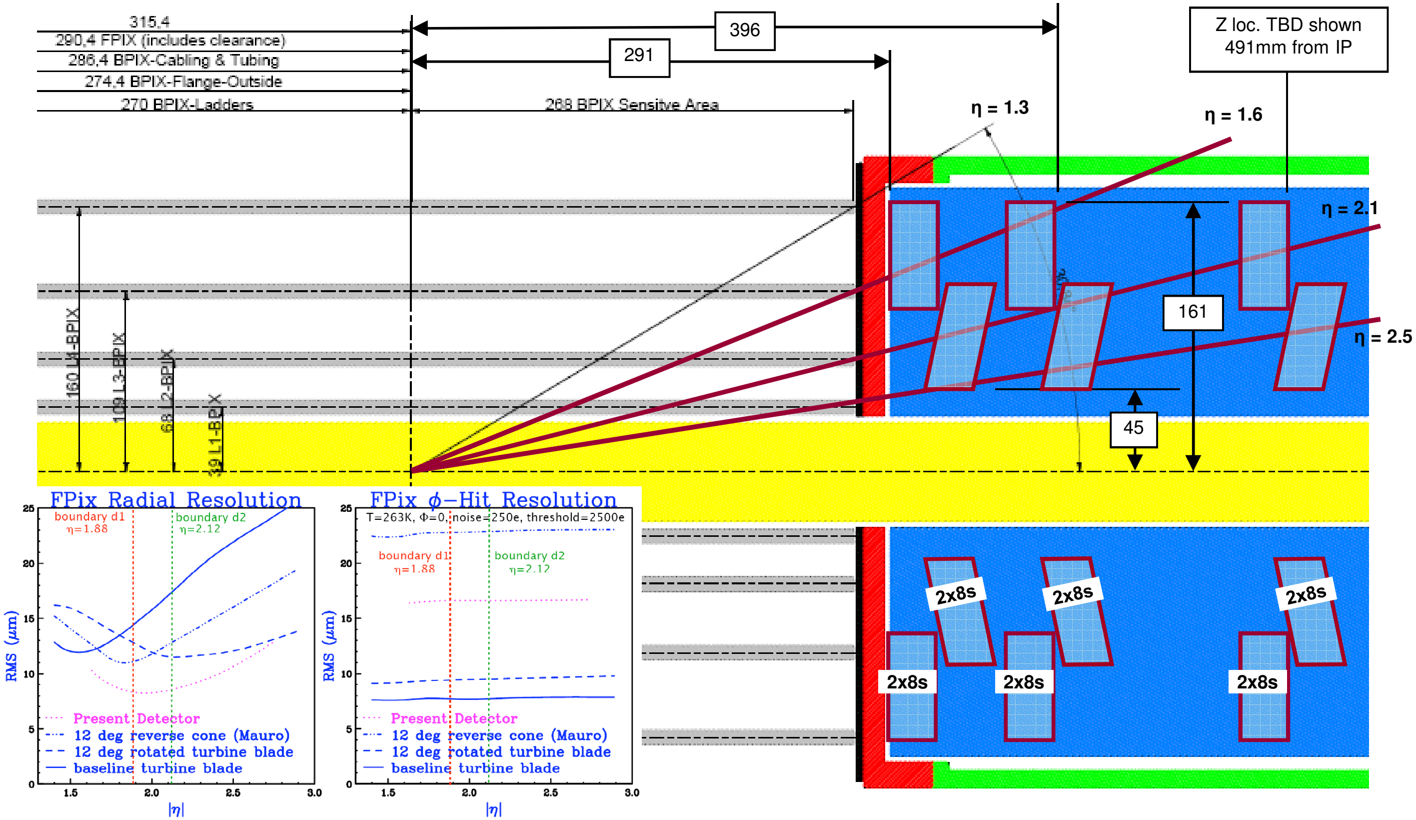
Baseline: 3 disks in each endcap

Use only ONE kind of module 2x8, and ONE identical blade.

- All modules are arranged radially and placed between r=45mm to 161mm (total 56 modules per half disk or 896 ROCs)
- Modules divided into an outer ring of 34 modules and inner ring of 22 modules
- Keep the same 20 degree rotation but for the inner assembly, add a 12 degree tilt to the IP (inverted cone geometry)

C02 cooling ;
Use thin-walled SS tubing 316 L and the size is tentatively chosen (1.638 mm OD, 1.435 mm ID) based on getting a continuous loop providing enough cooling power for each blade assembly.

Use ultra light weight materials for mechanical support and cooling (aim at material reduction of about a factor of 2)

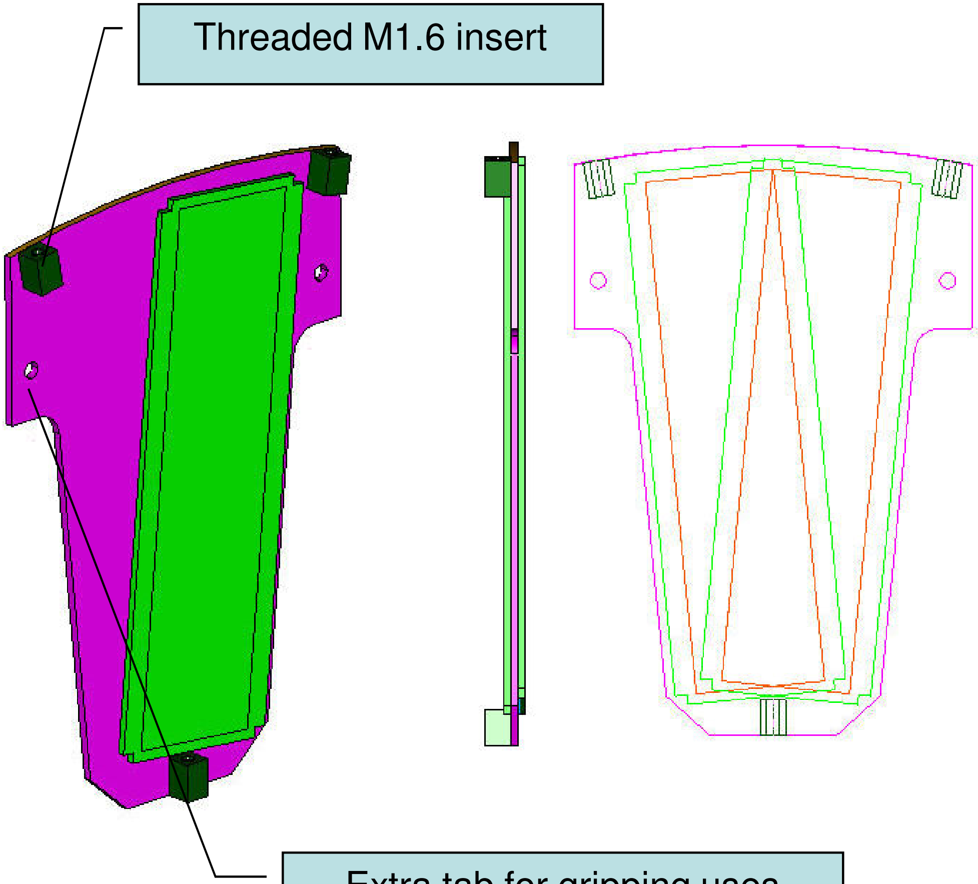


Based on Morris Swartz's study, it's possible to optimize the layout to obtain excellent resolution in both the azimuthal and radial directions throughout the FPix acceptance angle since we have separate inner and outer blade assemblies.

Inverted cone array combined with the 20 deg Rotated Vanes for the inner blade assembly is thus decided.

Basic Design of the Pixel Blade

- Solid TPG (0.88 mm thick, highly thermally conductive with inplane k = 1500 W/mK) encapsulated with carbon-fiber facing (0.06 mm thick).
- All blades are identical with one module on each side. (Only 2x8 module is used.)
- Cooling is arranged at the end of the blade in which good contact with the ring(s) is kept.
- 3 point mounting, 2 end support.
- Extra tabs are provided to facilitate in handling.
- Provisions (threaded screw) allows the blade to be attached/removed from the ring so no need to remove neighbors for removal (repair).

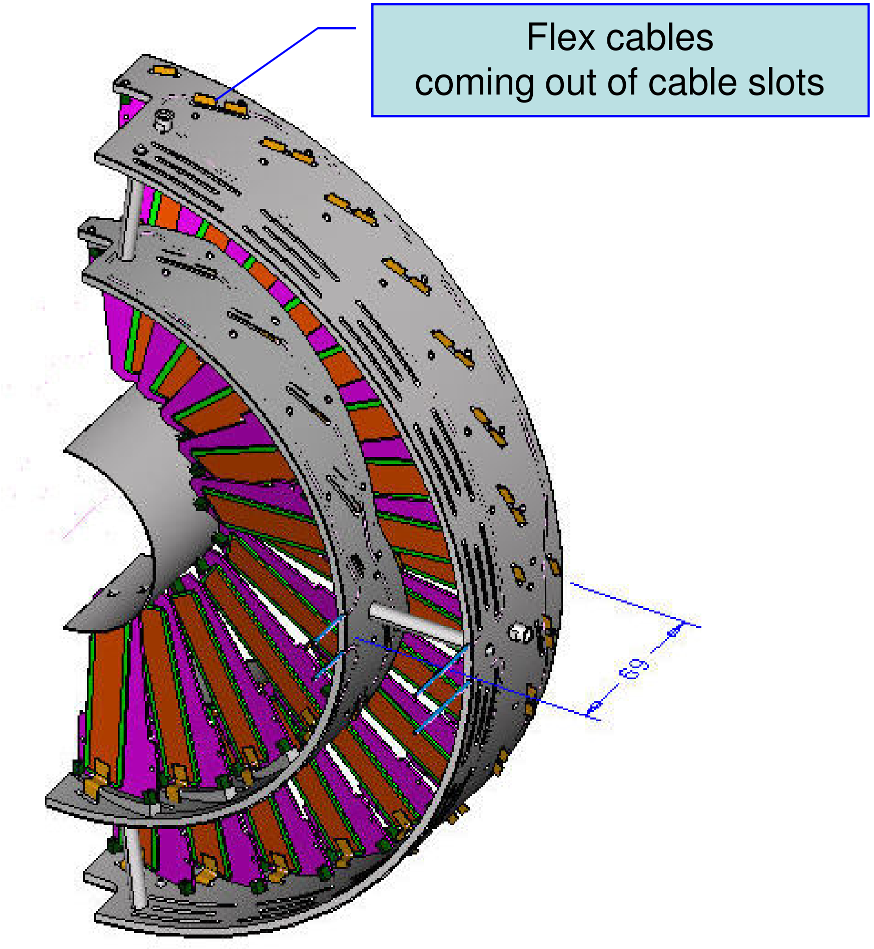


Threaded M1.6 insert

Extra tab for gripping uses during removal; Precision holes are used for module placement reference.

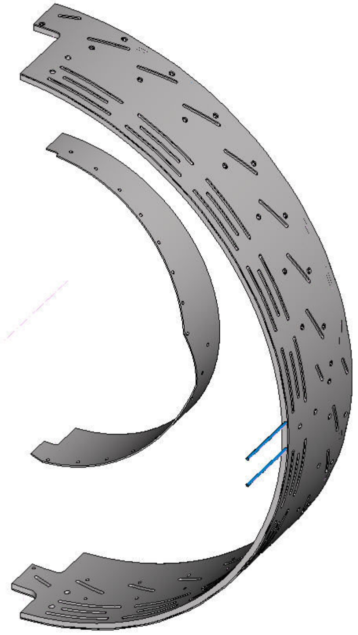
Basic Design of the Half Disk

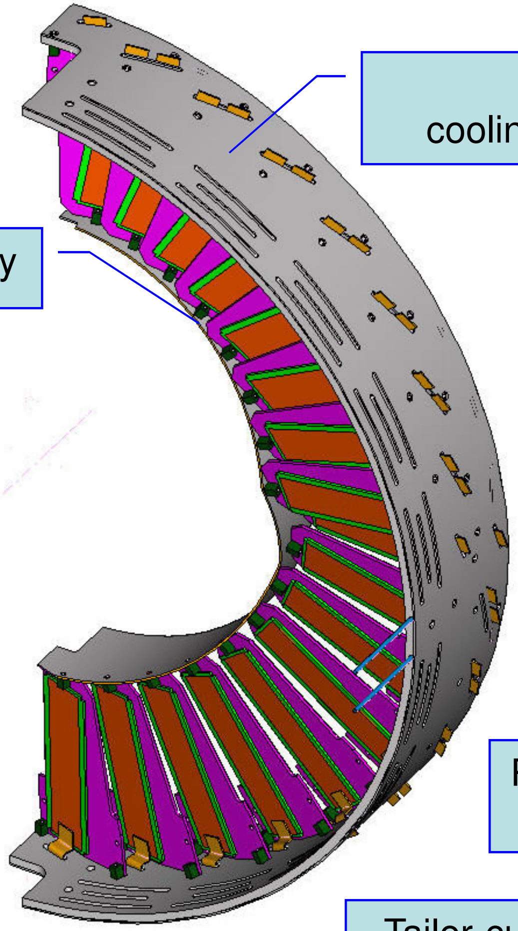
- Half disk consists of one inner blade assembly and one outer blade assembly and they are secured next to each other.
- Outer blade assembly consists of 17 blades.
- Inner blade assembly, with an inverted cone layout, consists of 11 blades and is supported by the outer blade assembly.
- Adjusted features for mounting identical blades are made in the inner blade assembly as identical blades are needed to fit in assemblies with different radii.
- All blades are supported by 2 rings;
- Cooling tube is embedded in the outer rings.


Flex cables
coming out of cable slots

Outer Blade Assembly

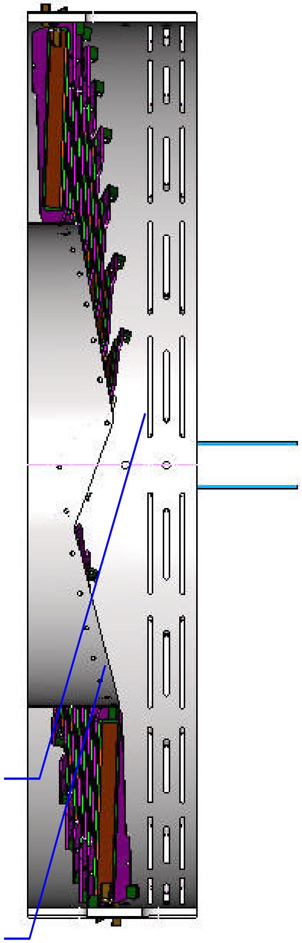
17 blades with Y-tilt 20° and Z offset = 2.2 mm, arranged in 2 rows
Closest distance btw neighboring blades = 5.5 mm
Ring width for inner ring = ~34 mm: Ring width for outer ring = 62 mm





Outer ring for cooling and support uses

inner ring for support uses only



Redundant cable slots for weight reduction

Tailor-cutting of the inner ring on this side for keeping the blade assemblies closer together

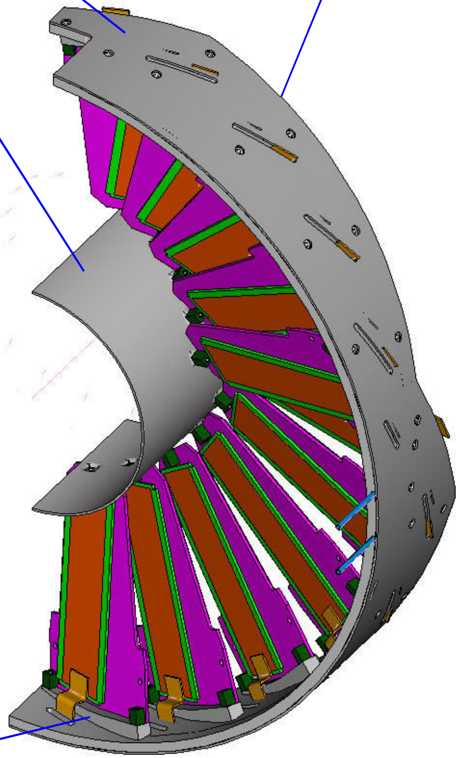
Inner Blade Assembly

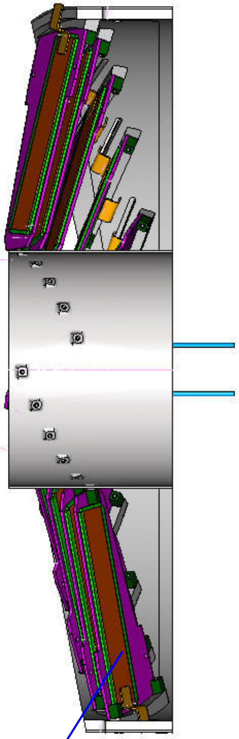
11 blades with Y-tilt 20° X-tilt 12° and Z offset = 4.5 mm, arranged in 2 rows
Closest distance btw neighboring blades = 5 mm
Ring width for inner ring = ~53.5 mm
Ring width for outer ring = 46.5 mm

Tailor-cutting of the inner ring on this side for keeping the blade assemblies closer together

Outer ring for cooling and support uses

Inner ring for support uses only

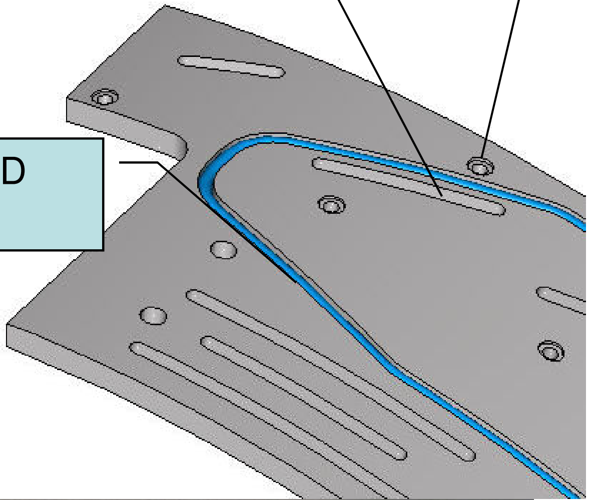




Elevated tabs for blade mounting

Inverted cone layout

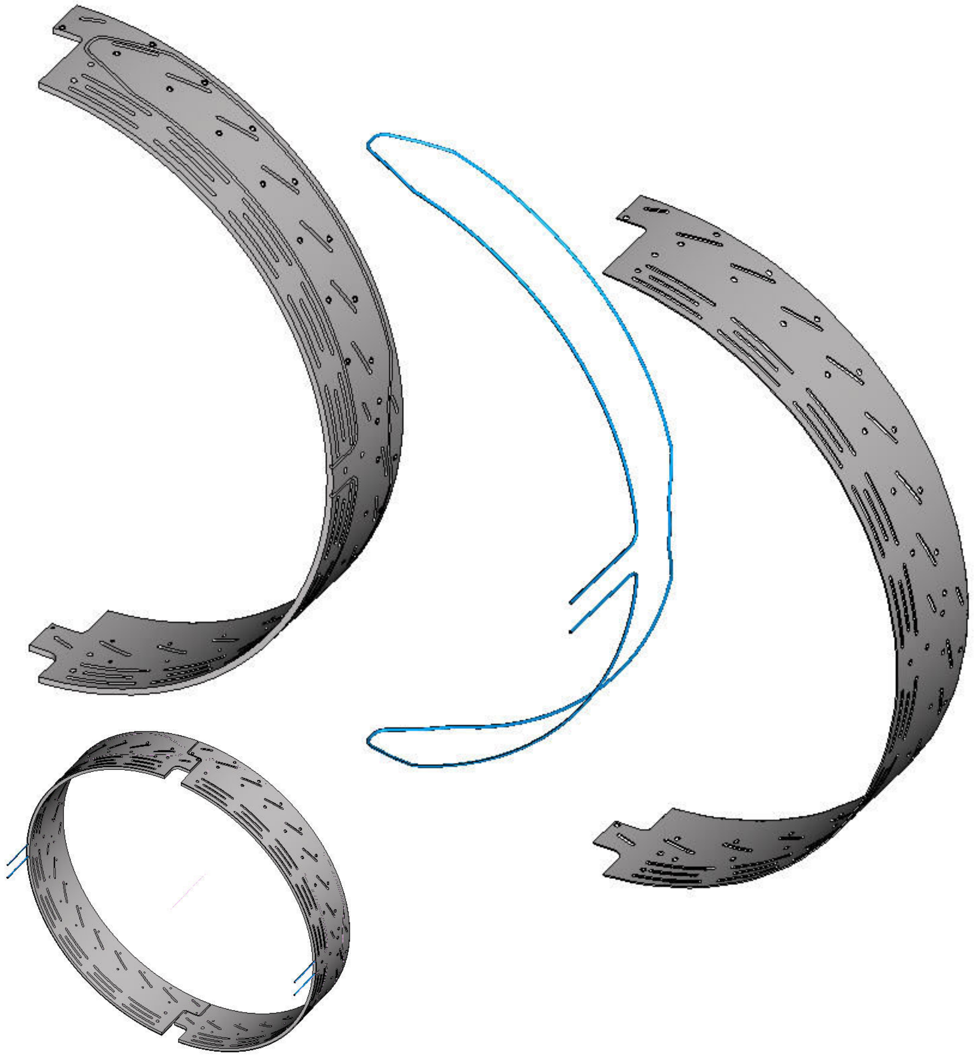
Outer Cooling Ring Assembly



2 mm X 20 mm cable slot

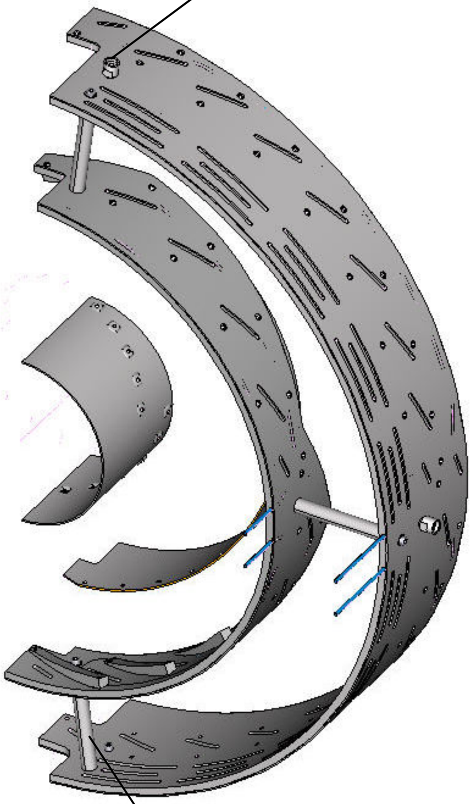
1.634 mm OD ss tubing

Thru' holes for mounting blades are not perpendicular to ring surface, spot face needed for screw head

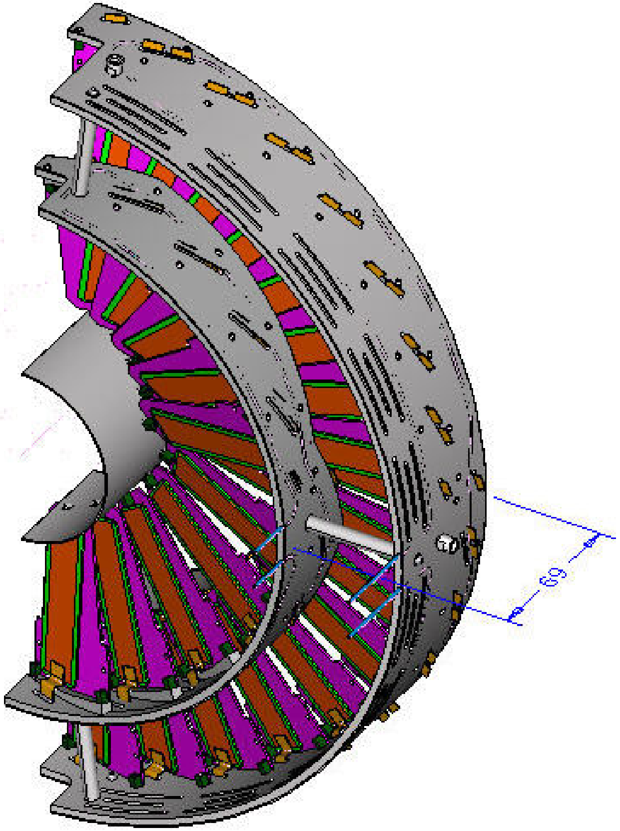


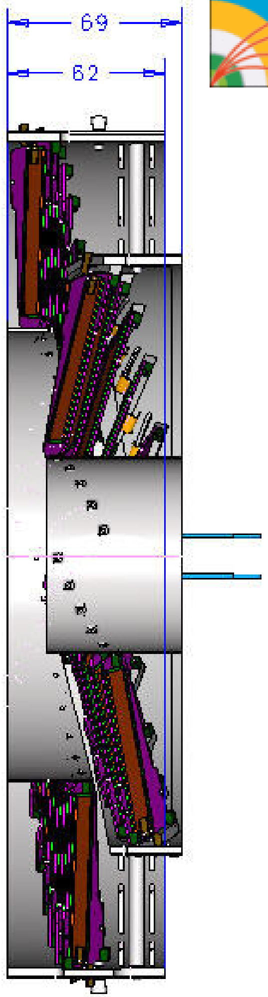
The Half Disk

Existing half disk mount design, 3 places

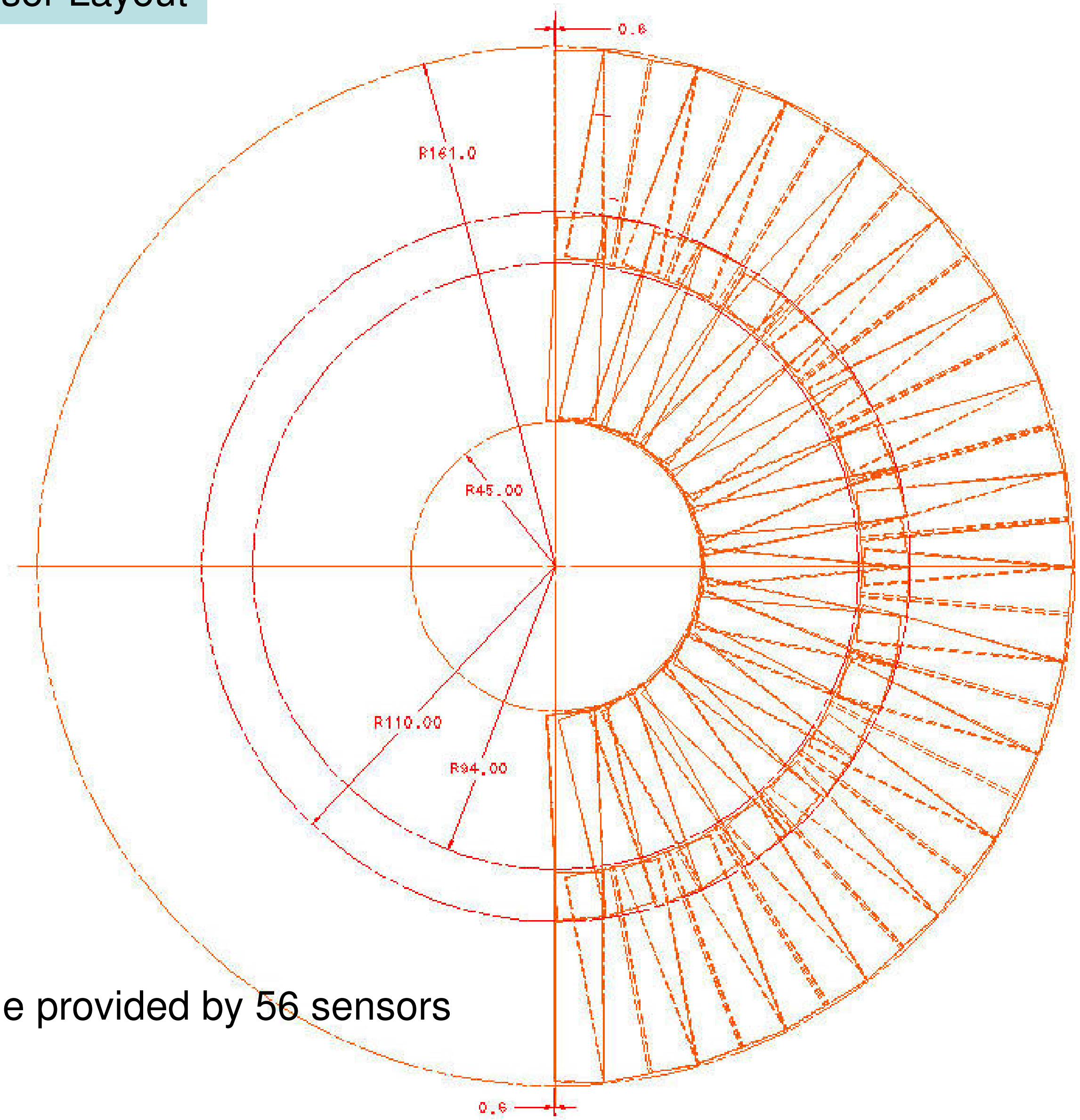


Carbon fiber tubing spike, threaded insert inside, 3 places





Half Disk Sensor Layout

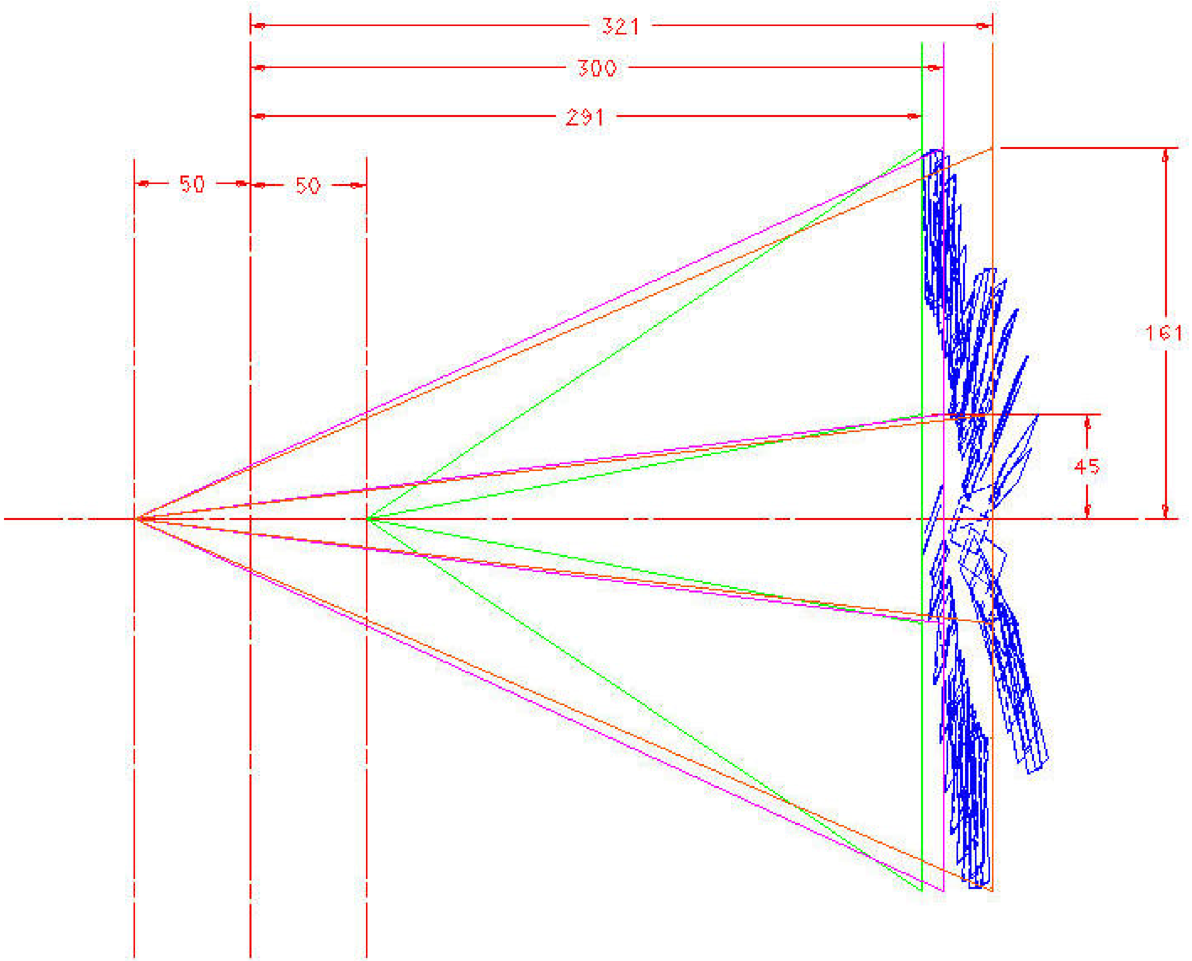


180° coverage provided by 56 sensors

Sensor Layout Coverage Check

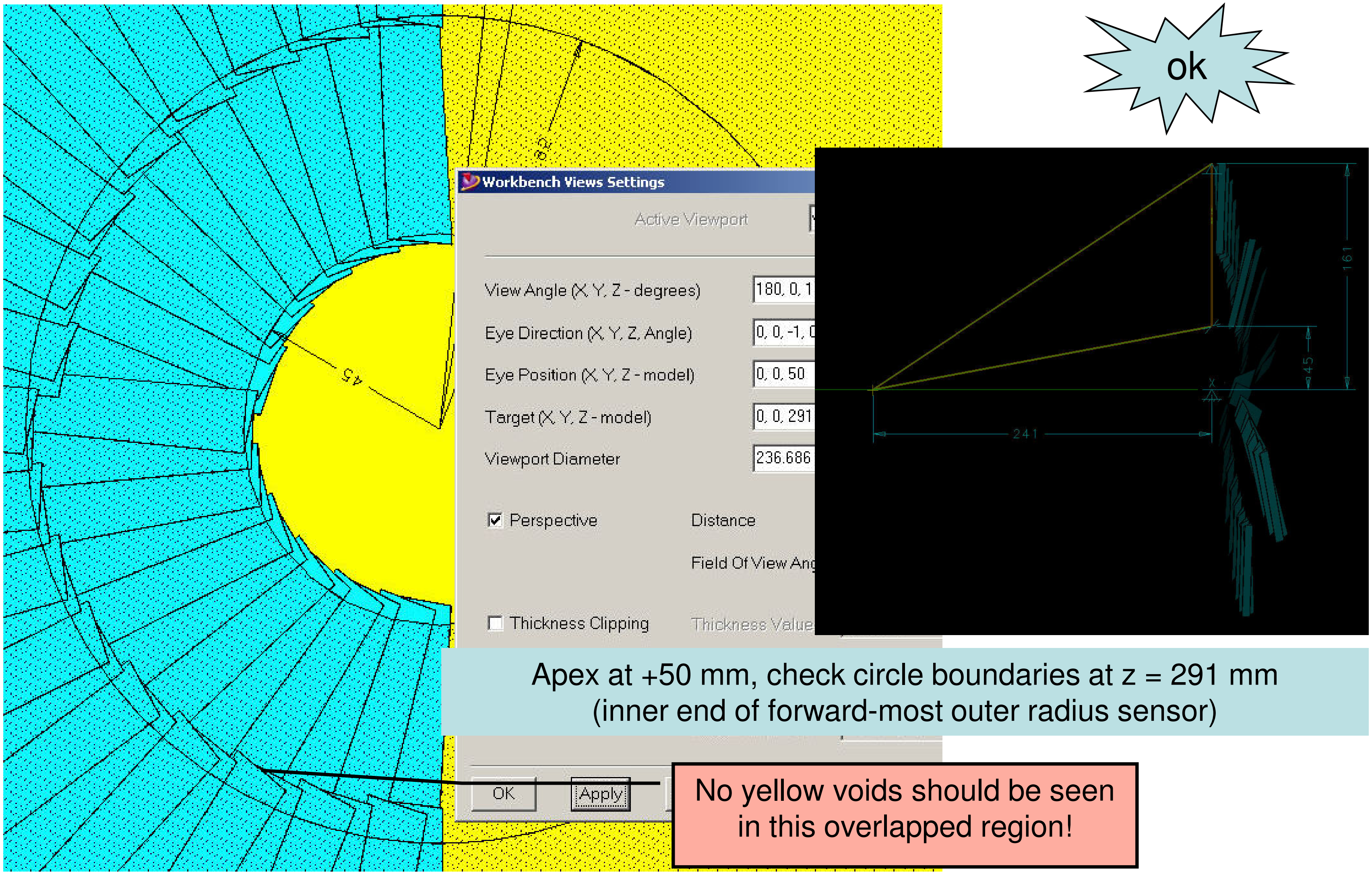
Use cones with base diameters equal to IR and OR in perspective views.

Outer boundary: apex at -50 mm and base at outer end of backward-most outer radius sensor
Inner boundary: apex at -50 mm and base at inner end of forward-most inner radius sensor
Overlap between outer and inner: apex at +50 mm and base at inner end of forward-most outer radius sensor



Perspective View of First Half Disk Sensors Coverage
IR 45 mm, OR 161 mm
Region to be checked: Overlap between inner and outer

ok



Workbench Views Settings

Active Viewport

View Angle (X, Y, Z - degrees) 180, 0, 1

Eye Direction (X, Y, Z, Angle) 0, 0, -1, 0

Eye Position (X, Y, Z - model) 0, 0, 50

Target (X, Y, Z - model) 0, 0, 291

Viewport Diameter 236.686

☑ Perspective

Distance

Field Of View Ang

☐ Thickness Clipping

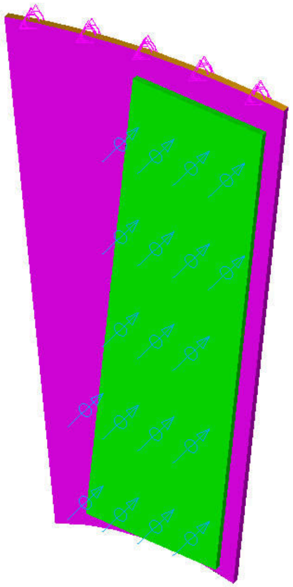
Thickness Value

OK Apply

Apex at +50 mm, check circle boundaries at z = 291 mm
(inner end of forward-most outer radius sensor)

No yellow voids should be seen
in this overlapped region!

FEA Check on Blade with Two 2x8 Modules



Blade thickness:
0.06 mm cf + 0.88 mm TPG + 0.06 mm cf

Multi-chip thickness (overall .900 mm):
- Adhesive: .050 mm
- ROC: .200 mm
- Bump-Bond: .030 mm
- Sensor: .270 mm
- HDI: .300 mm

Simplified model:
- ROC were a continous layer instead of 16 tiny ones;
- Bump-bonds were modeled as a continuous isotropic layer;
- HDI was modeled as a continous isotropic layer;

Flexible silicone glue was used for all adhesion layers

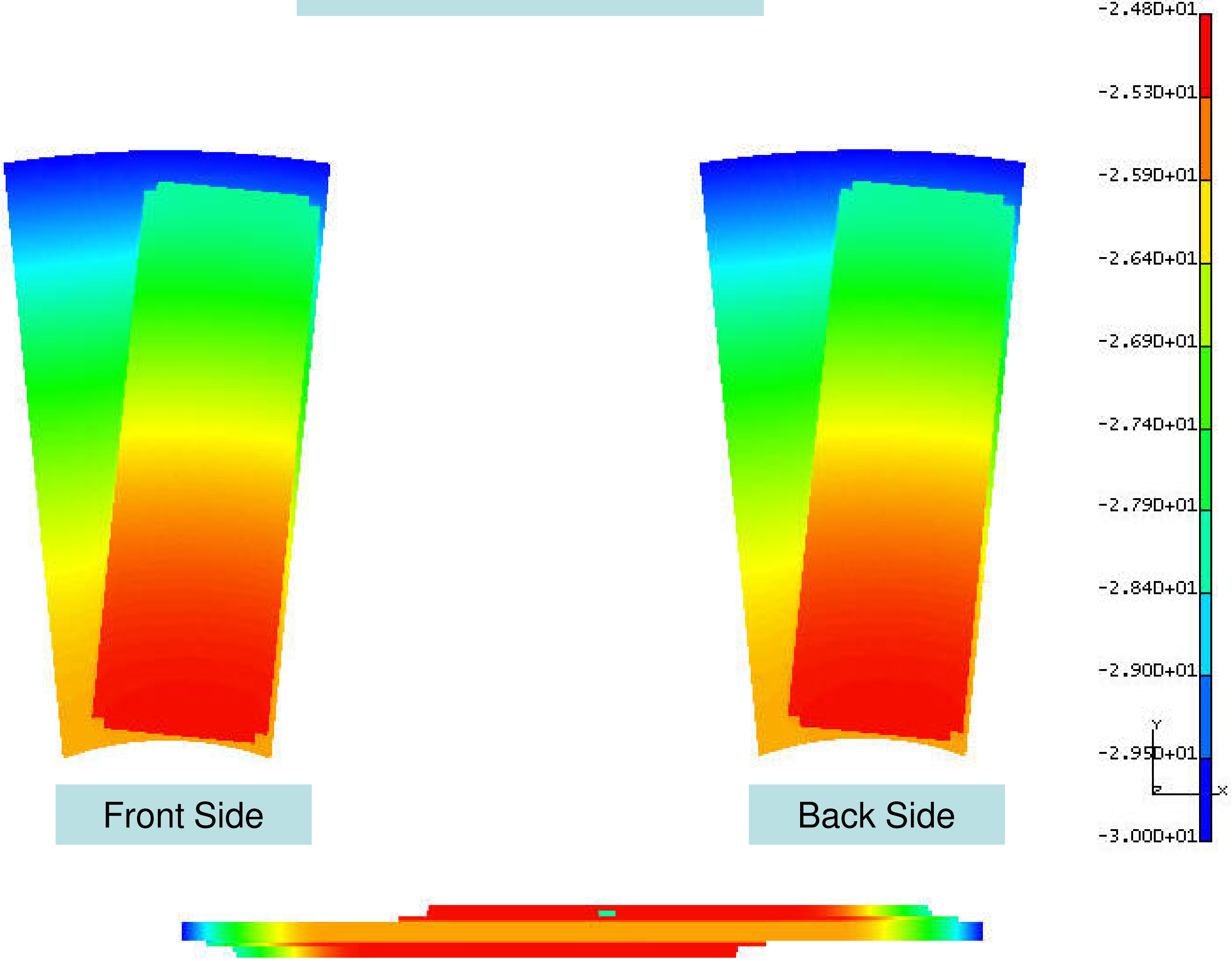
Temperature was set fixed at end(s) of blade at -30C

Total heat load on blade = 7.3 W. (150%; Expected heat load with a 50% overload as safety margin).

0.06 cf + 0.88 TPG + 0.06 cf Blade
150% heat load, 7.3W per blade;
sensor: 0.6 W; ROC: 6.7 W

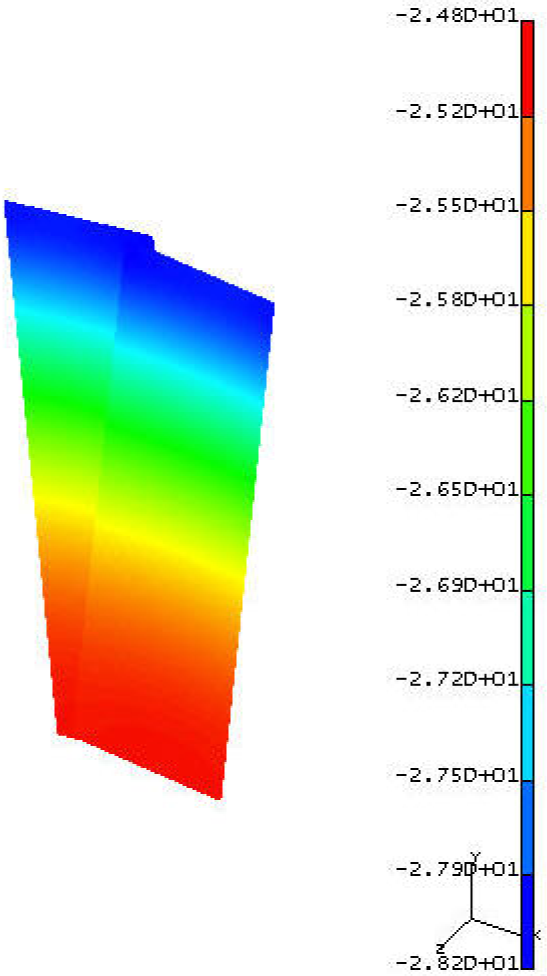
Heat sink on outer edge only
HDI being the outermost within module

ΔT = 5.2C across model

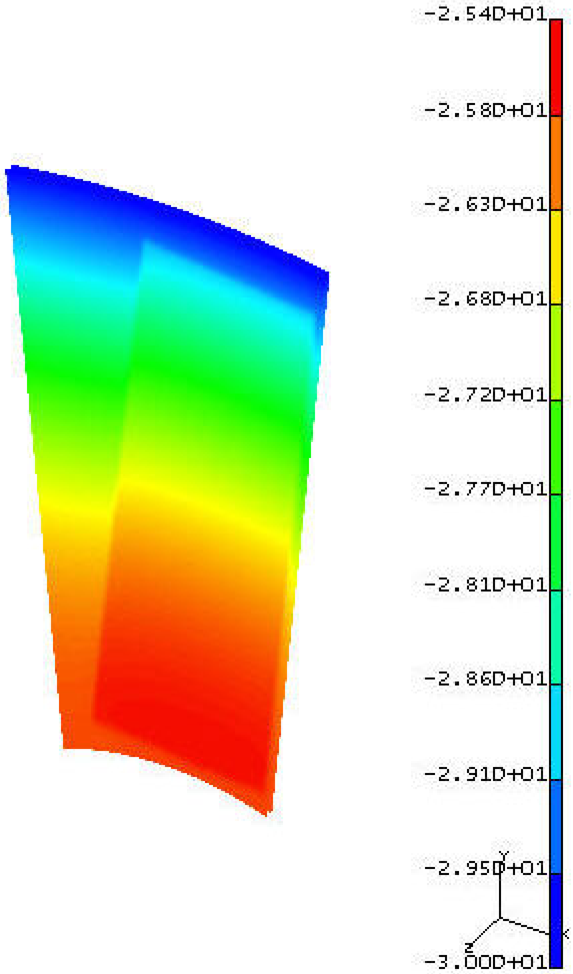


0.06 cf + 0.88 TPG + 0.06 cf Blade
150% heat load, 7.3W per blade;
sensor: 0.6 W; ROC: 6.7 W

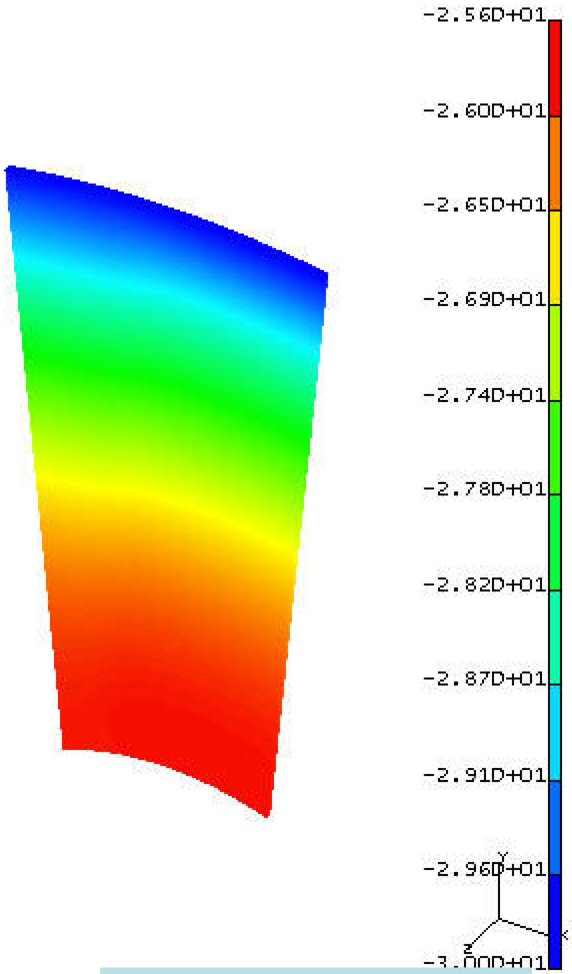
Heat sink on outer edge only
HDI being the outermost within module



ΔT = 3.5C across sensor



ΔT = 4.6C across CF

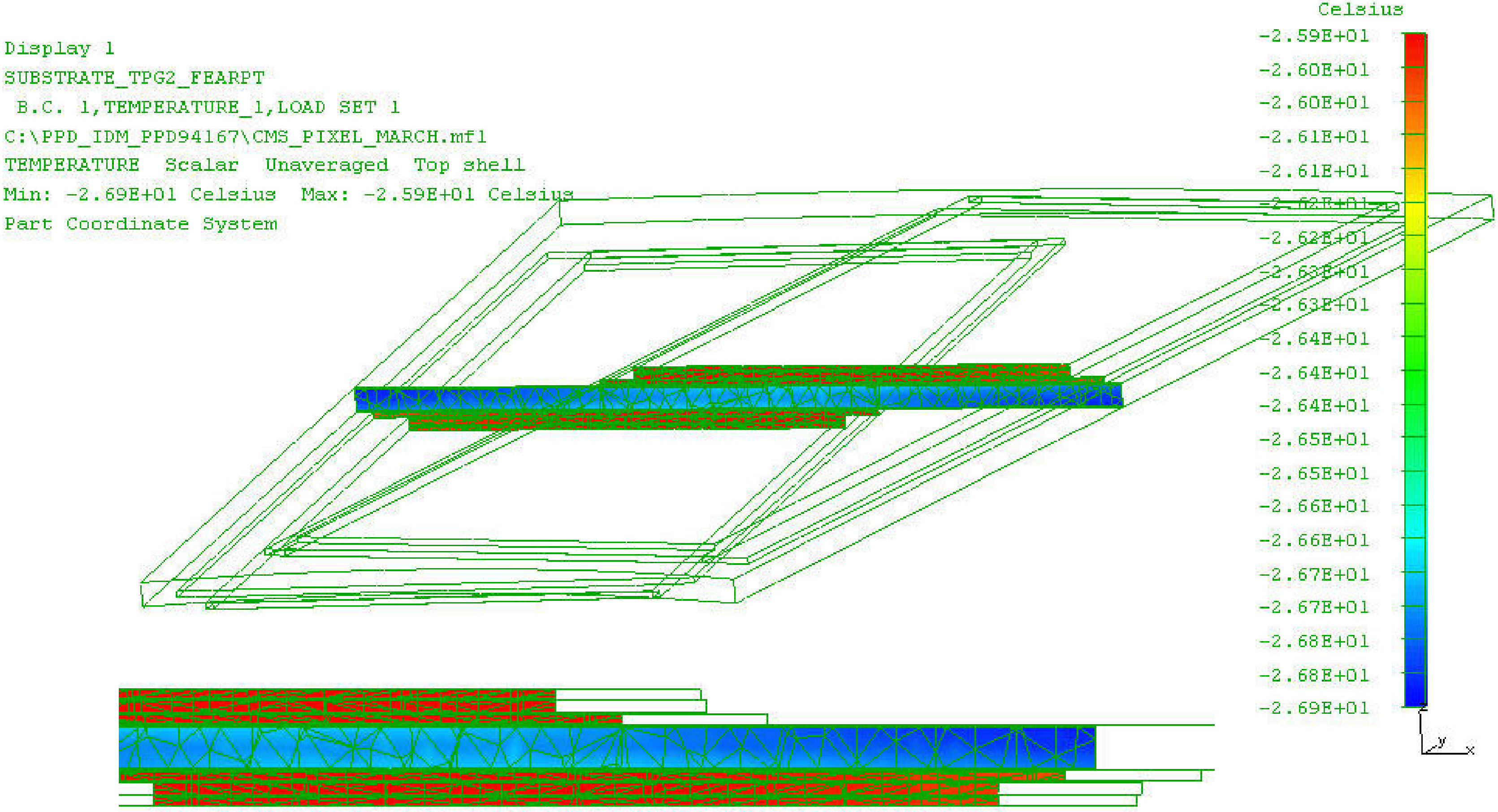


ΔT = 4.4C across TPG

0.06 cf + 0.88 TPG + 0.06 cf Blade

150% heat load, 7.3W per blade;
sensor: 0.6 W; ROC: 6.7 W

Heat sink on outer edge only
HDI being the outermost within module



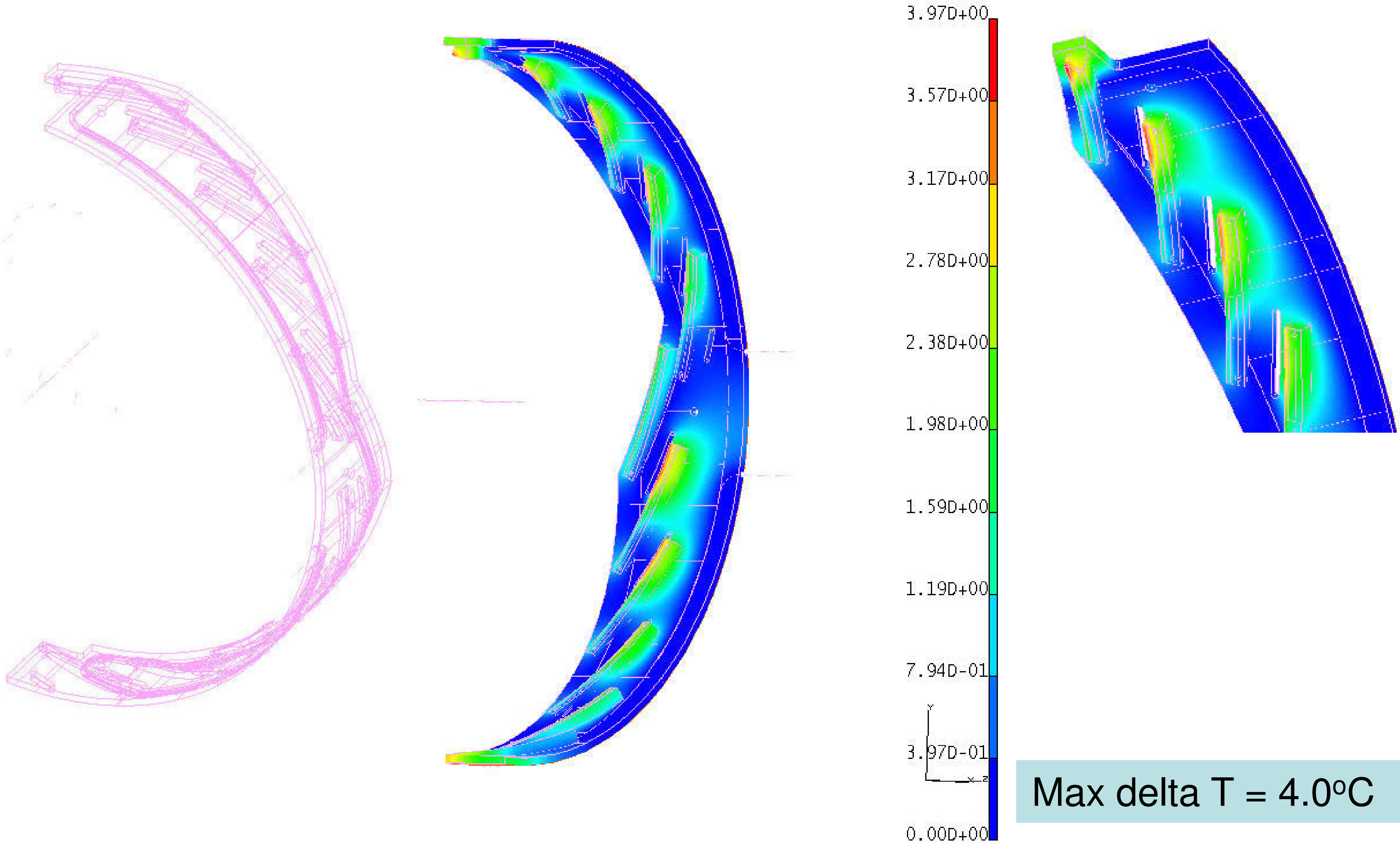
```
Display 1
SUBSTRATE_TPG2_FEARPT
 B.C. 1,TEMPERATURE_1,LOAD SET 1
C:\PPD_IDM_PPD94167\CMS_PIXEL_MARCH.mfl
TEMPERATURE  Scalar  Unaveraged  Top shell
Min: -2.69E+01 Celsius  Max: -2.59E+01 Celsius
Part Coordinate System
```

ΔT = 1.0C
across the mid-cut section

Carbon Carbon Cooling Half Rings FEA

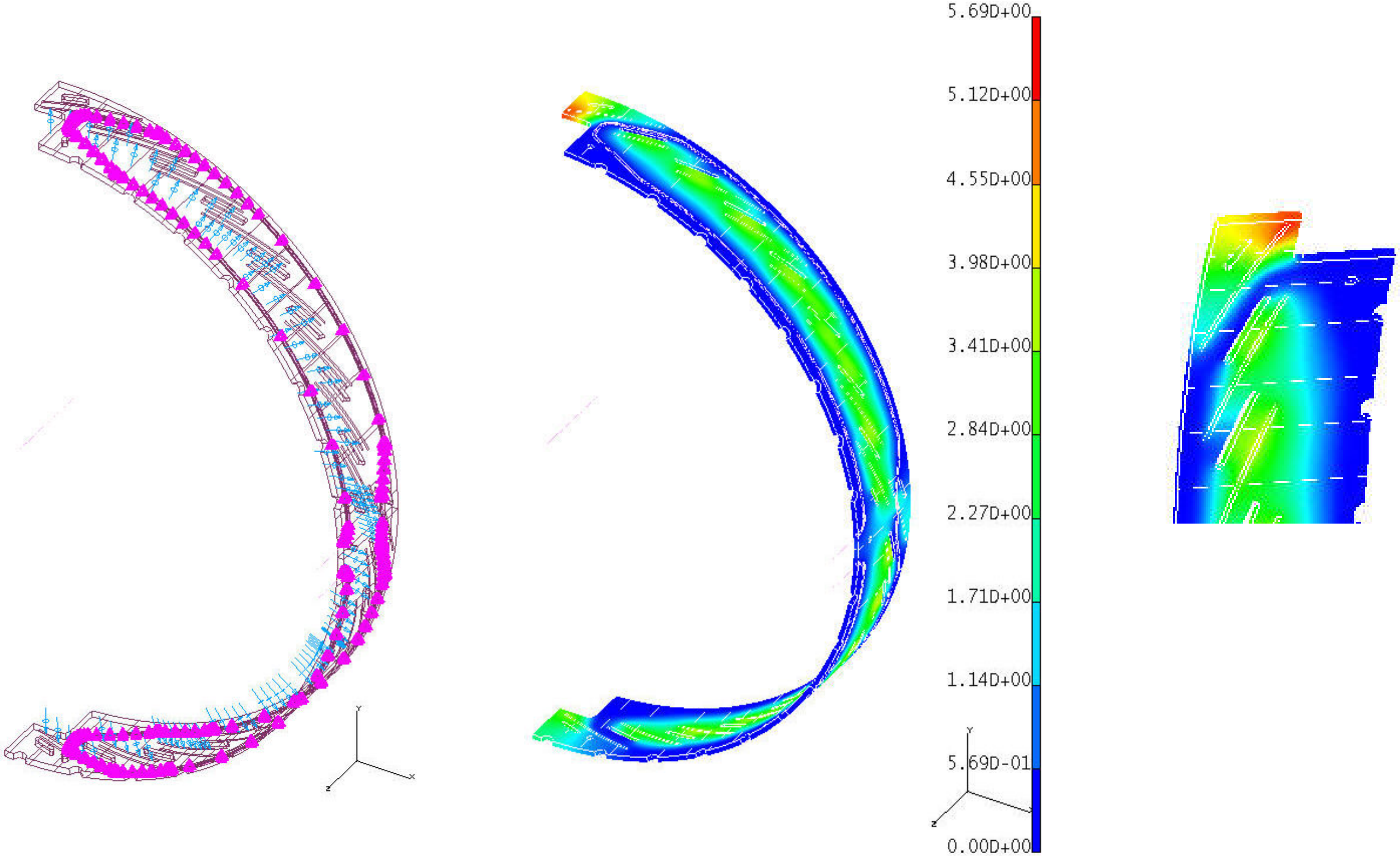
- Thermal conductivities of CC:
    - KX = 200, KY = 150, KZ = 200 W/mK
- Nominal thickness of CC ring = 2.5 mm
- For successful FEA meshing, the FEA models were simplified:
    - some holes or some cut-outs for the holes, were skipped.
    - some locations of the cable slots were shifted slightly
- Total heat load: 124 W for outer ring and 80 W for inner ring. (Expected heat load with a 50% overload as safety margin i.e. 150% heat load).
- 0^{o}C was tentatively used and applied on the wall of the groove to see the delta temperature across the ring.

Inner Half Ring
150% heat load, 7.3 W per blade, total 80 W



Max delta T = 4.0°C

Outer Half Ring
150% heat load, 7.3 W per blade, total 124 W



Max delta T = 5.7^{o}C at tip
Max delta T = ~3^{o}C in most regions

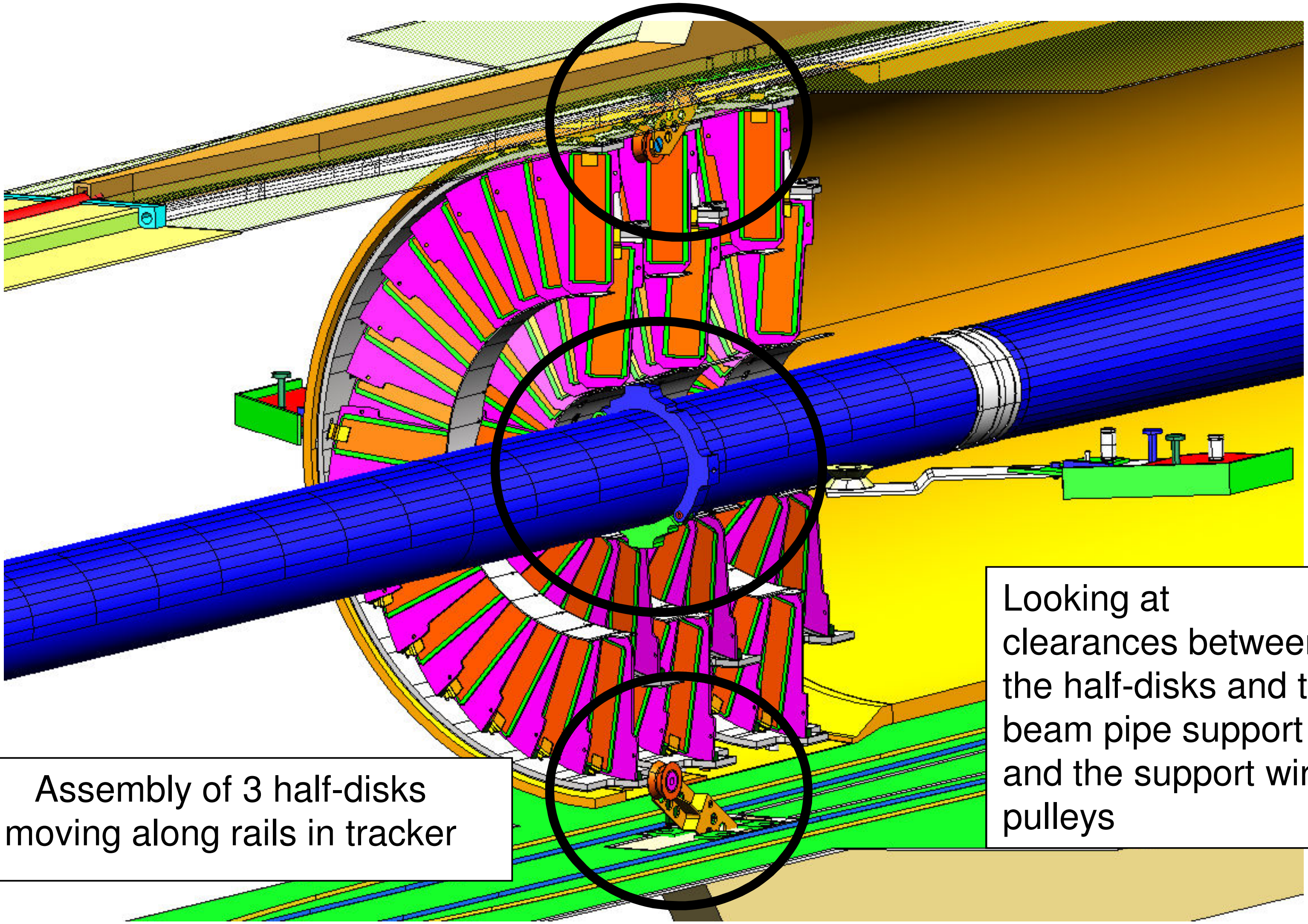
Material Budget Estimate

Material Budget according to conceptual design 10/28/09

All masses are distribued evenly over an effective overlapped substrate area =					5990	mm^2	(15-degree coverage)	
	material	t or L, mm	area, mm^2	volume, mm^3	density, g/cc	mass, g	X0, g/cm^2	Eff. % Rad L
TPG	TPG	0.880	5990	5271	2.26	11.913	42.7	0.47%
CF facing	CF	0.120	5990	719	1.76	1.265	42.8	0.05%
Sub total % RL for substrate								**0.51%**
Outer tubing	ss 316L	1101		538	7.82	0.281	14.1	0.03%
Outer ring	CC	2.5		68830	1.80	8.260	42.7	0.32%
Outer skin	CF	0.12		3470	1.76	0.407	42.8	0.02%
Outer inner ring	CF	0.5		3507	1.76	0.412	42.8	0.02%
Inner tubing	ss 316L	740		361	7.82	0.188	14.1	0.02%
Inner ring	CC	2.5		38423	1.80	4.611	42.7	0.18%
Inner skin	CF	0.12		1566	1.76	0.184	42.8	0.01%
Inner inner ring	CF	0.5		3199	1.76	0.375	42.8	0.01%
Spokes	CF			2677	1.76	0.314	42.8	0.01%
Sub total %RL for supporting and cooling								**0.63%**
Total								**1.14%**

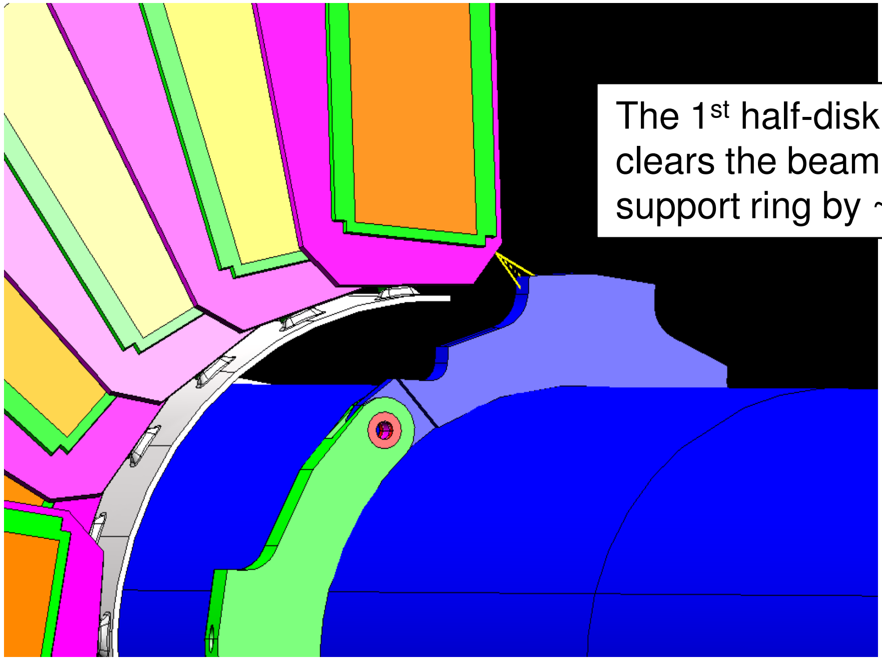
`Existing Berylium Design`					
Substrates X2	4278	1.85	7.914	65.2	0.28%
Cooling Channel	3261	2.7	8.805	24.0	0.86%
Coolant	2588	1.79	4.633	34.8	0.31%
Sub-Total for substrate					**1.45%**
Outer Ring	1774	2.7	4.790	24.0	0.47%
Inner Ring	796	2.7	2.149	24.0	0.21%
Sub-Total for support					**0.68%**
VHDI (substrate + kapton + coppe etc.)					**0.93%**
Total without VHDI					**2.13%**
Total with VHDI					**3.06%**

Clearance Check

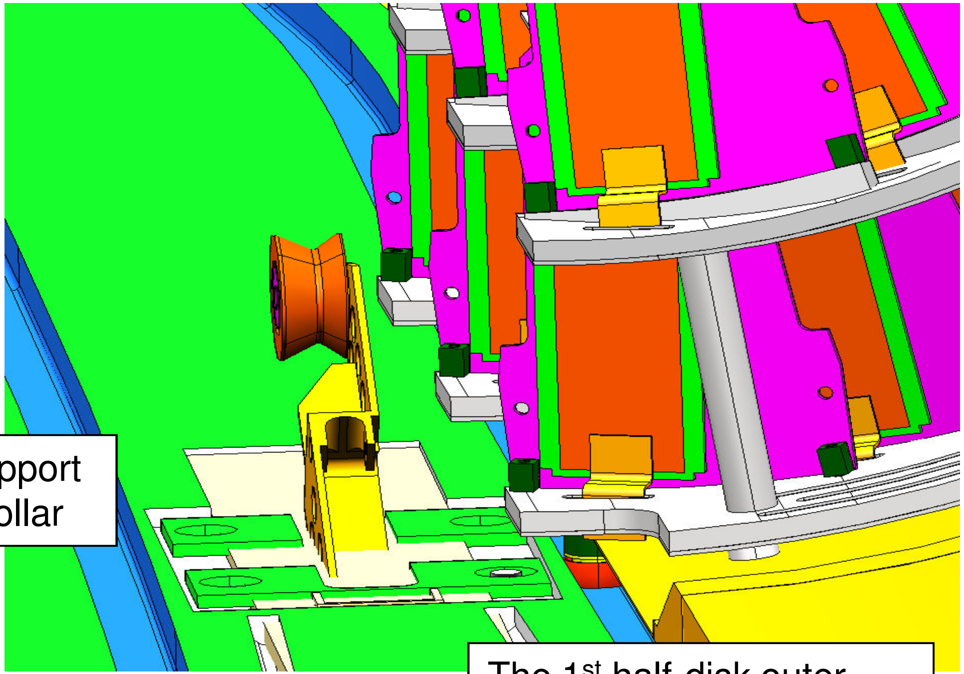


Assembly of 3 half-disks moving along rails in tracker

Looking at clearances between the half-disks and the beam pipe support and the support wire pulleys



The 1st half-disk top panel clears the beam pipe support ring by ~ 3.8 mm



(narrow) wire support for beam pipe collar

The 1st half-disk outer ring clears the narrow pulley by ~ 3.8 mm

Summary

- A conceptual design was made.
- Some FEAs were run to verify the thermal performance.
- Some prototypes like the TPG substrate, and parts for the outer ring assembly including rings and ss tubing were made.

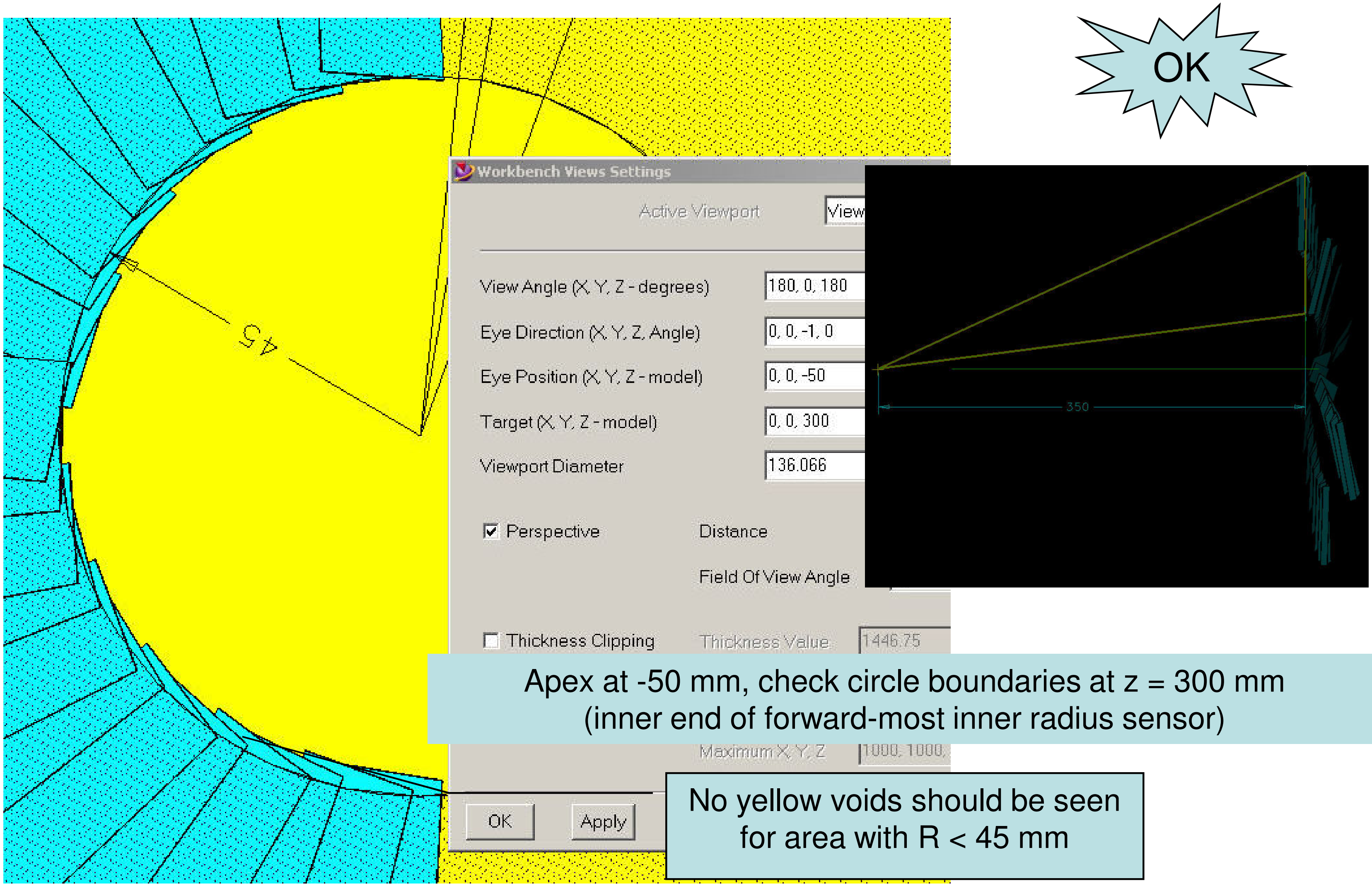
Next Steps

- Optimize the CC ring design to reduce the weight further.
- Run FEA to verify stresses and distortions on TPG substrate etc.
- Run flow test.
- Fabricate more prototypes including CC ring prototypes.
- Conduct thermal test on TPG substrate, and CC ring.

Back Up Slides

Perspective View of First Half Disk Sensor Coverage
IR 45 mm, OR 161 mm
Region to be checked: inner boundaries

OK



Workbench Views Settings

Active Viewport: View

View Angle (X, Y, Z - degrees): 180, 0, 180

Eye Direction (X, Y, Z, Angle): 0, 0, -1, 0

Eye Position (X, Y, Z - model): 0, 0, -50

Target (X, Y, Z - model): 0, 0, 300

Viewport Diameter: 136.066

☑ Perspective

Distance

Field Of View Angle

☐ Thickness Clipping

Thickness Value: 1446.75

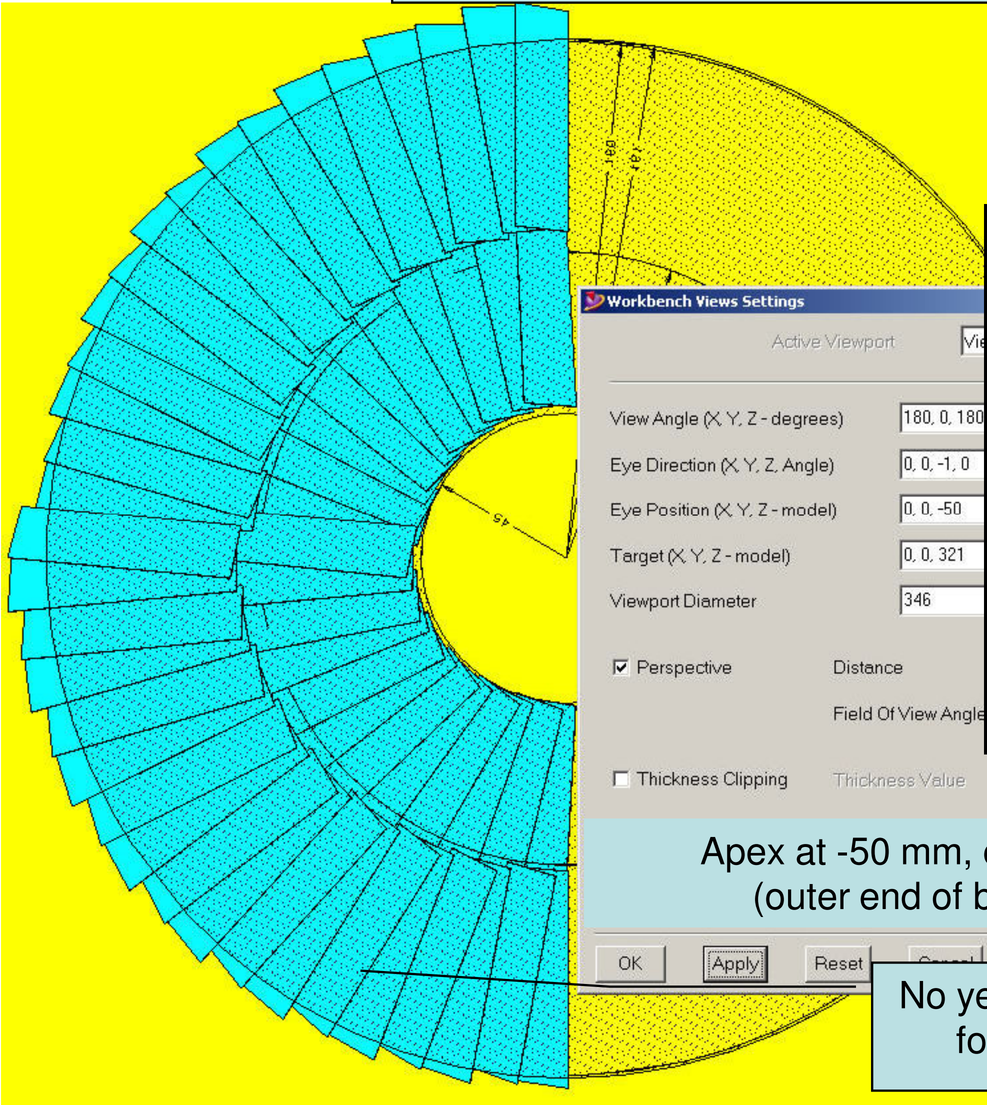
Maximum X, Y, Z: 1000, 1000,

Apex at -50 mm, check circle boundaries at z = 300 mm
(inner end of forward-most inner radius sensor)

No yellow voids should be seen
for area with R < 45 mm

Perspective View of First Half Disk Sensors Coverage
IR 45 mm, OR 161 mm
Region to be checked: outer boundaries

OK



Workbench Views Settings

Active Viewport: Vie

View Angle (X Y, Z - degrees): 180, 0, 180

Eye Direction (X, Y, Z, Angle): 0, 0, -1, 0

Eye Position (X, Y, Z - model): 0, 0, -50

Target (X, Y, Z - model): 0, 0, 321

Viewport Diameter: 346

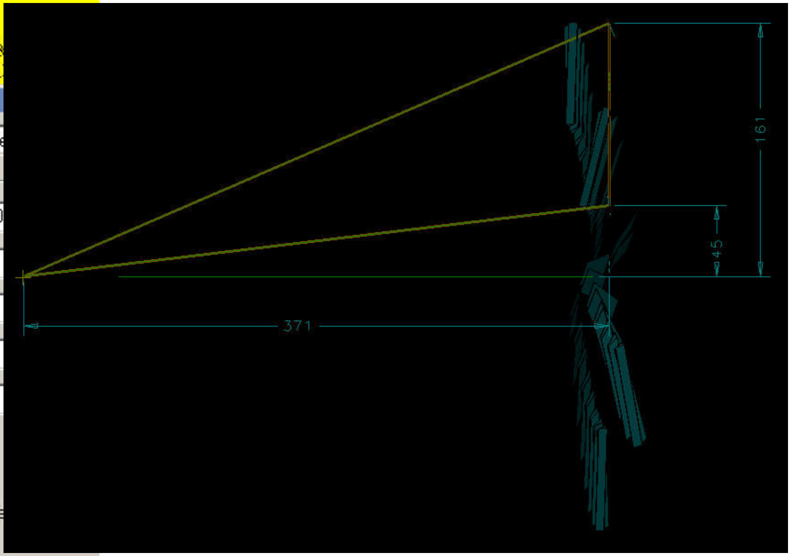
☑ Perspective

Distance

Field Of View Angle

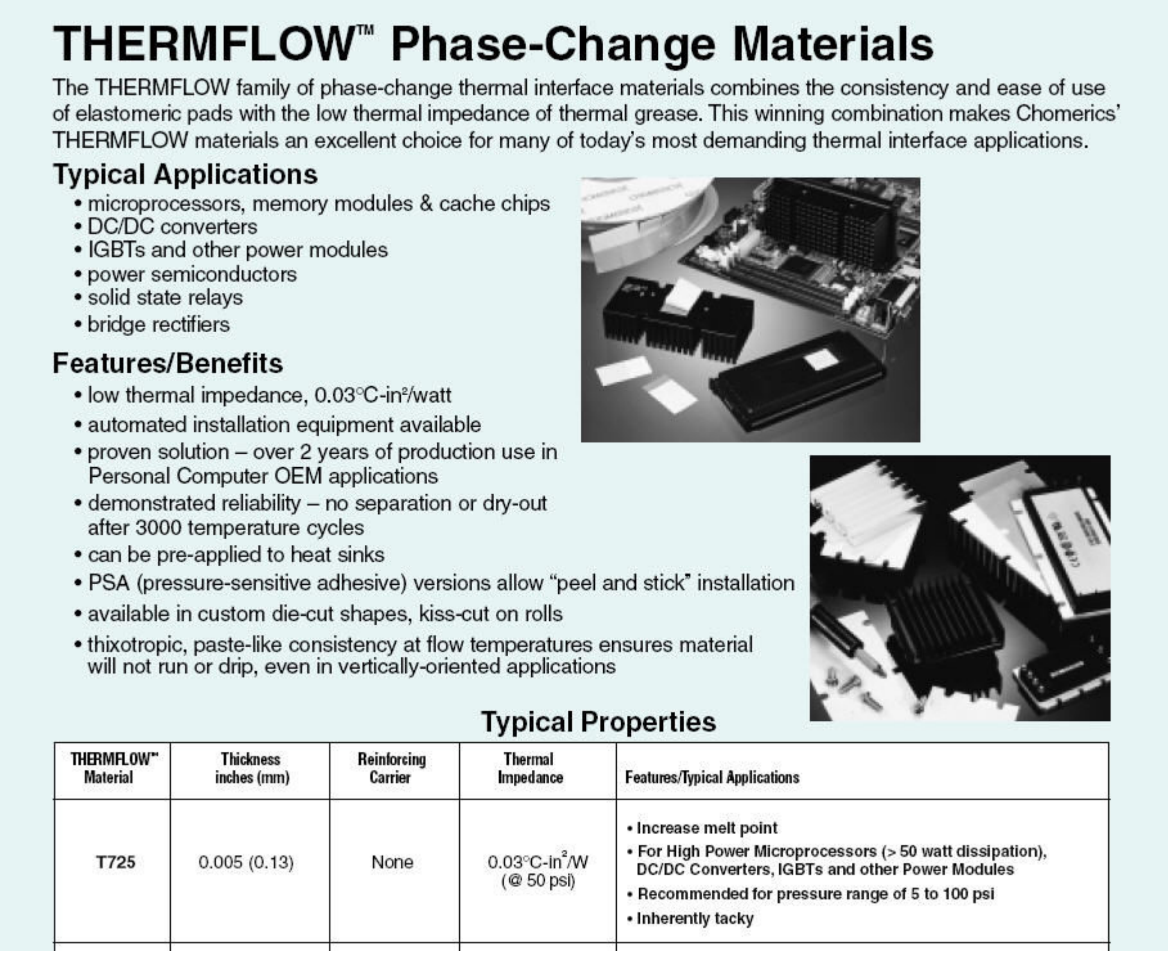
☐ Thickness Clipping

Thickness Value: 1121.2



Apex at -50 mm, check circle boundaries at z = 321 mm
(outer end of backward-most outer radius sensor)

No yellow voids should be seen
for area with R< 161 mm



THERMFLOW™ Phase-Change Materials

The THERMFLOW family of phase-change thermal interface materials combines the consistency and ease of use of elastomeric pads with the low thermal impedance of thermal grease. This winning combination makes Chomerics' THERMFLOW materials an excellent choice for many of today's most demanding thermal interface applications.

Typical Applications

- microprocessors, memory modules & cache chips
- DC/DC converters
- IGBTs and other power modules
- power semiconductors
- solid state relays
- bridge rectifiers

Features/Benefits

- low thermal impedance, 0.03°C-in²/watt
- automated installation equipment available
- proven solution – over 2 years of production use in Personal Computer OEM applications
- demonstrated reliability – no separation or dry-out after 3000 temperature cycles
- can be pre-applied to heat sinks
- PSA (pressure-sensitive adhesive) versions allow "peel and stick" installation
- available in custom die-cut shapes, kiss-cut on rolls
- thixotropic, paste-like consistency at flow temperatures ensures material will not run or drip, even in vertically-oriented applications

Typical Properties

THERMFLOW™ Material	Thickness inches (mm)	Reinforcing Carrier	Thermal Impedance	Features/Typical Applications
T725	0.005 (0.13)	None	0.03°C-in²/W (@ 50 psi)	• Increase melt point • For High Power Microprocessors (> 50 watt dissipation), DC/DC Converters, IGBTs and other Power Modules • Recommended for pressure range of 5 to 100 psi • Inherently tacky

heat, W =	7.3
x width, mm	1.0
x length, mm	45.0
x area, in^2 =	0.1
film ht, in =	0.003
impedance, (°C in2 / Watt)	0.05
delta T =	5.2
thermal k, W/m-K =	2.362

impedance, (°C in2 / Watt)	0.03
delta T =	3.1

Silicone base material

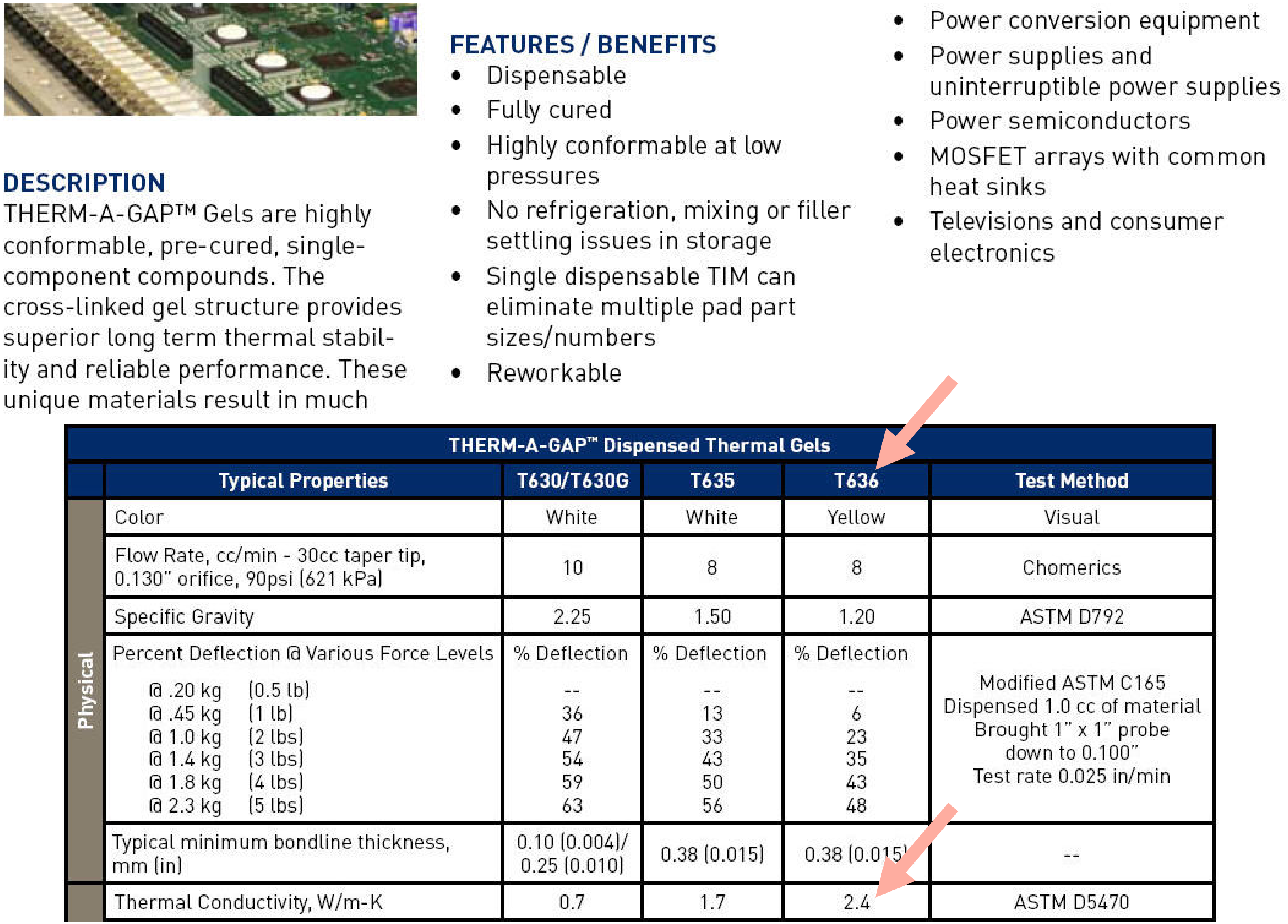
Solid at room temperature for easy handling and installation

Soften when operating temperature reached (or need burn-in at 55C)

Completely fill interfacial air gaps and voids

Could attain bond-line thickness 1 mil ~ 3 mils

LHCb Vertex Locator has been planning to use this product.



DESCRIPTION

THERM-A-GAP™ Gels are highly conformable, pre-cured, single-component compounds. The cross-linked gel structure provides superior long term thermal stability and reliable performance. These unique materials result in much

FEATURES / BENEFITS

- Dispensable
- Fully cured
- Highly conformable at low pressures
- No refrigeration, mixing or filler settling issues in storage
- Single dispensable TIM can eliminate multiple pad part sizes/numbers
- Reworkable

- Power conversion equipment
- Power supplies and uninterruptible power supplies
- Power semiconductors
- MOSFET arrays with common heat sinks
- Televisions and consumer electronics

THERM-A-GAP™ Dispensed Thermal Gels

	Typical Properties	T630/T630G	T635	T636	Test Method
Physical	Color	White	White	Yellow	Visual
	Flow Rate, cc/min - 30cc taper tip, 0.130" orifice, 90psi (621 kPa)	10	8	8	Chomerics
	Specific Gravity	2.25	1.50	1.20	ASTM D792
	Percent Deflection @ Various Force Levels	% Deflection	% Deflection	% Deflection	Modified ASTM C165 Dispensed 1.0 cc of material Brought 1" x 1" probe down to 0.100" Test rate 0.025 in/min
	@ .20 kg (0.5 lb)	--	--	--	
	@ .45 kg (1 lb)	36	13	6	
	@ 1.0 kg (2 lbs)	47	33	23	
	@ 1.4 kg (3 lbs)	54	43	35	
	@ 1.8 kg (4 lbs)	59	50	43	
	@ 2.3 kg (5 lbs)	63	56	48	
	Typical minimum bondline thickness, mm (in)	0.10 (0.004)/ 0.25 (0.010)	0.38 (0.015)	0.38 (0.015)	--
	Thermal Conductivity, W/m-K	0.7	1.7	2.4	ASTM D5470

Rapid Prototyping

- Stereolithography (SLA) is often considered the pioneer of the Rapid Prototyping industry with the first commercial system introduced in 1988 by 3D Systems. The system consists of an Ultra-Violet Laser, a vat of photo-curable liquid resin, and a controlling system.
- A platform is lowered into the resin (via an elevator system), such that the surface of the platform is a layer-thickness below the surface of the resin. The laser beam then traces the boundaries and fills in a two-dimensional cross section of the model, solidifying the resin wherever it touches. Once a layer is complete, the platform descends a layer thickness, resin flows over the first layer, and the next layer is built. This process continues until the model is complete.
- Once the model is complete, the platform rises out of the vat and the excess resin is drained. The model is then removed from the platform, washed of excess resin, and then placed in a UV oven for a final curing. The model is then finished by smoothing the "stair-steps."
- Maximum dimensions for instant quotes: 25"x25"x21".
- SLA Layer Thickness: High Resolution: 0.002” - 0.004”; Standard Resolution: 0.005” - 0.006”.

Material Candidates for Substrate

	Density g/cc	Modulus, E_ab Gpa	Modulus, E_c Gpa	Strength Mpa	Thermal K_ab W/m-K	Thermal K_c W/m-K	cte_ab ppm/K	cte_c ppm/K	Rad L, X0 cm
Porous Materials									
fuzzy C, 5% pr	0.11	-	-		-	55	-	1.0	406.7
carbon foam, low density	0.25	0.9			15	20	3.5		170.8
SiC foam, 8% packing ratio	0.26	2.8	2.8		11	11	2.2	2.2	166.1
RVC foam (vitreous C)	0.30	0.1	0.1	0.3	0.5	0.5	2.2	2.2	142.3
carbon foam, medium density	0.35	3.0		-1.6	20	25	3.5		122.0
carbon foam, high density	0.45	5.0		-3.5	25	40	3.5		94.9
poco-foam, 25% pr	0.55	20.7	20.7	-2.07	45	135	2.5	2.5	77.6
rohacell	0.03	0.0	0.0	1	0.0	0.0	37.0	37.0	1497.7
Solid Non-metalic Materials									
pyrolitic graphite, PGS	1				600	15.0	0.9	32.0	42.7
peek	1.32	3.6	3.6	92.9	0.2	0.2	46.8	46.8	35.0
CoolPoly E5101 (PPS)	1.70	13.0	13.0	45.0	20	20	15.0	15.0	26.5
CFRP (M46J-epoxy)	1.61	18.1	7.3		56	0.7	0.0	30.2	26.5
glassy C	1.65	20.0	20.0		5	5	3.0	3.0	25.9
CFRP (K13C2U-epoxy)	1.75	483.0	6.2		320	0.5	-1.0	26.0	24.4
CFRP (K139-EX1515)	1.76	154.0	6.4		63	0.4	-0.8	30.4	24.3
Poco graphite ACF-10Q	1.77	11.0	11.0	69.0	60	60	7.6	7.6	24.1
C-C composite (carbon fiber/carbon matrix)	1.80	152.0	4.8		225	150	2.0	2.0	23.7
SiC	3.21	466.0	466.0	-3900	40	40	3.3	3.3	8.1
G10 (glass fiber/epoxy)	1.8	17.2		262.0	0.3	0.3	11.9	11.9	19.4
pyrolitic graphite, TPG	2.26	18.7*	0.0		1700*	10	-1.0	25.0	18.9
Alumina Silicate	2.80			17.5	1.2	1.2	2.9	2.9	14.2
Vespel SP1 Polyimide	1.43	2.4	2.4	87.3	0.3	0.3	54.0	54.0	31.9
CVD Diamond	3.51	1000.0	1000.0	400.0	2000	2000	1.0	1.0	12.0
DLC (diamond-like carbon) coating									
Solid Metalic									
Be	1.85	290.0	290.0	276	145	145	11.6	11.6	35.4
AlBeMet	2.10	200.0	200.0	192	210	210	13.9	13.9	16.1
BeO	2.90	345.0	345.0	138000	330	330	7.6	7.6	13.3
Aluminum Nitride (AIN)	3.26	331.0	331.0	-2100	165	165	4.5	4.5	10.3
silicon	2.33	110.3	110.3	-120	120	120	2.6	2.6	9.4
aluminum 6061-T6	2.76	69.0	69.0	379	237	237	23.4	23.4	8.9
stainless steel 304	7.86	200.0	200.0	517	16	16	15.1	15.1	1.8
copper 101	8.94	129.7	129.7	350	391	391	17.6	17.6	1.4

Material Library in this FEA

All materials were assumed to be isotropic with constant properties except

- TPG
- CFRP and
- bump bonds

TPG Thermal K

Temp in K		K in W/m-K
70	# #	2920
80	# #	3432
90	# #	3784
100	# #	3984
150	# #	3624
200	# #	2600
250	# #	1960
273.2	# #	1784
300	# #	1600
350	# #	1352
400	# #	1168
500	# #	904
600	# #	744

	Modulus	Thermal K	CTE
Materials	Mpa	W/m-K	ppm/K
HDI	30000	0.26	17
Sensor & ROC	110000	124	2.6
Bump Bond (x, y / z)*	0.15 / 1500	0.00033 / 2.38	24.7
Silicone Glue	2	0.24	100
CFRP (x / y, z)	446000 / 6460	126 / 0.62	-1 / 33.6
TPG (x, y / z)	17000 / 0.16	see table / 10	-1 / 3

HDI consisted of several layers of copper, kapton and adhesive. The final design of this HDI was not known yet.
It was temporarily modeled as 1 layer of material with the effective properties as shown.

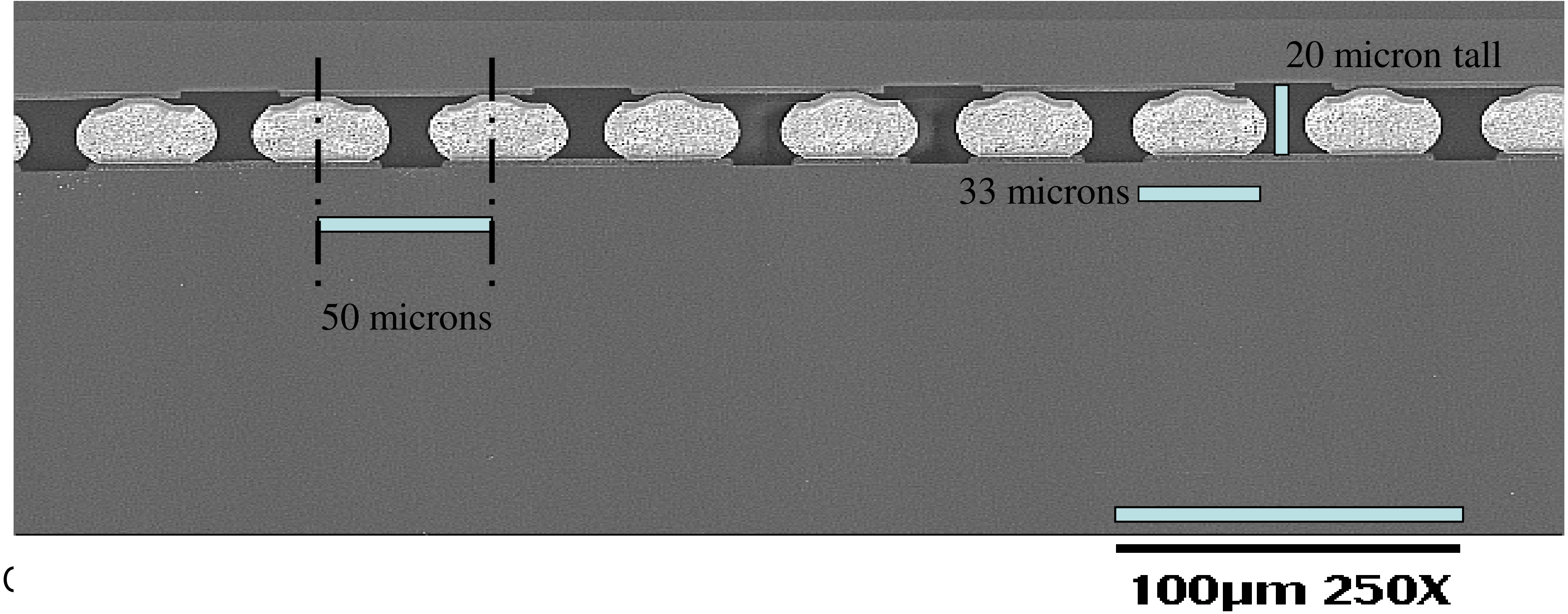
The Modeling of Bump Bonds

It is difficult to model the tiny bump bonds, beam elements were once used with all rotational constraints, but it appeared too stiff.

Used equivalent method, modeled bonds as continuous and homogenous material over the entire area.
There were about 52x80 bump bonds per chip, it thus had an area ratio of bonds/ROC about 1/21.33. Properties were then adjusted with this ratio for running FEA in the out of plane direction and a negligible small number for the in plane direction, and the corresponding reported stresses for bump bond would be multiplied by 21.33.

Effective E = Ebond/21.33, effective k = kbond/21.33, effective cte = ctebond

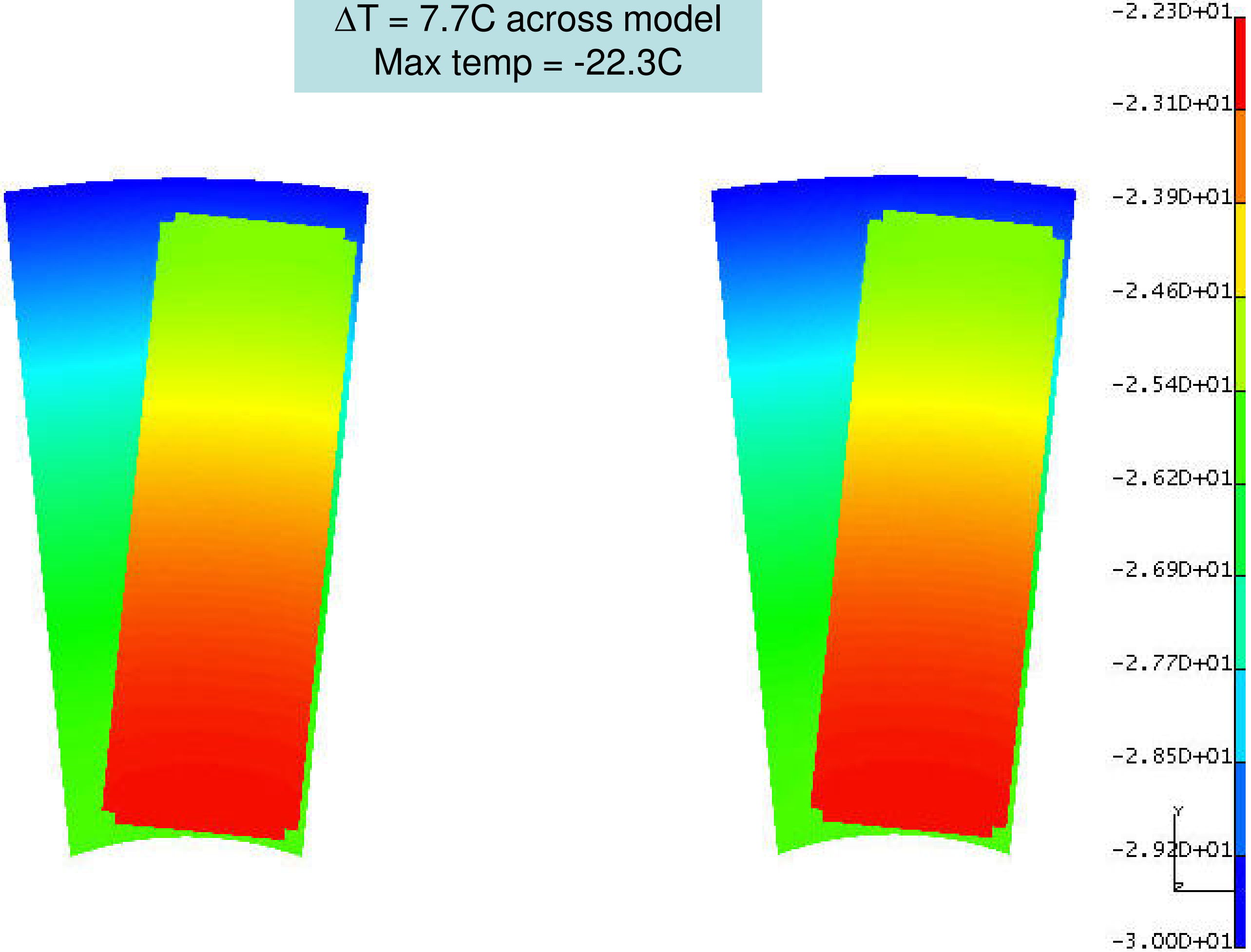
The effective material properties used in this FEA were:
$E_x = E_z = 0.15$ Mpa, $E_y = 1500$ Mpa, $k_x = k_z = 0.33\text{e-}3$ W/mK, $k_y = 2.38$ W/mK, $a = 24.7\text{e-}6$ ppm/C



0.06 cf + 0.88 TPG + 0.06 cf Blade
150% heat load, 7.3W per blade;
sensor: 0.6 W; ROC: 6.7 W

Configuration (2)
Heat sink on outer edge only
HDI glued next to the substrate

ΔT = 7.7C across model
Max temp = -22.3C

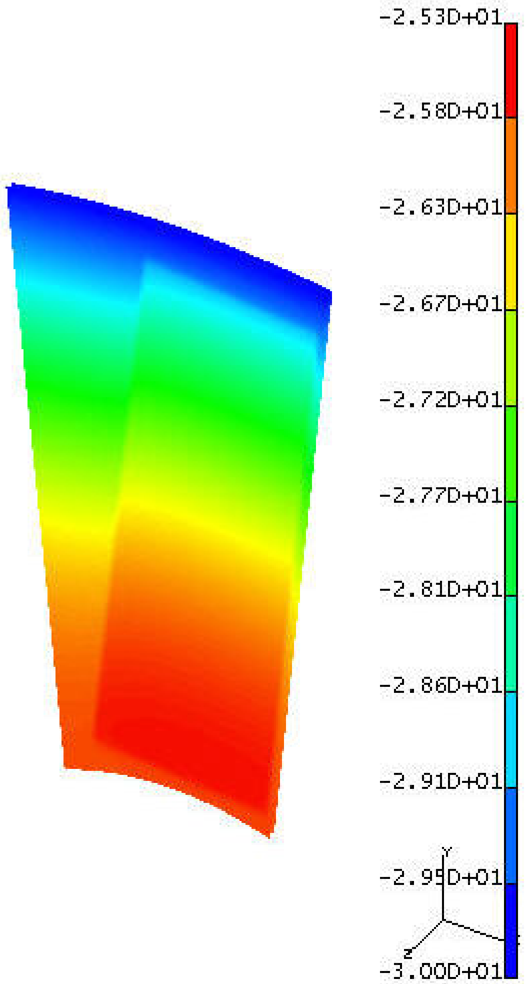


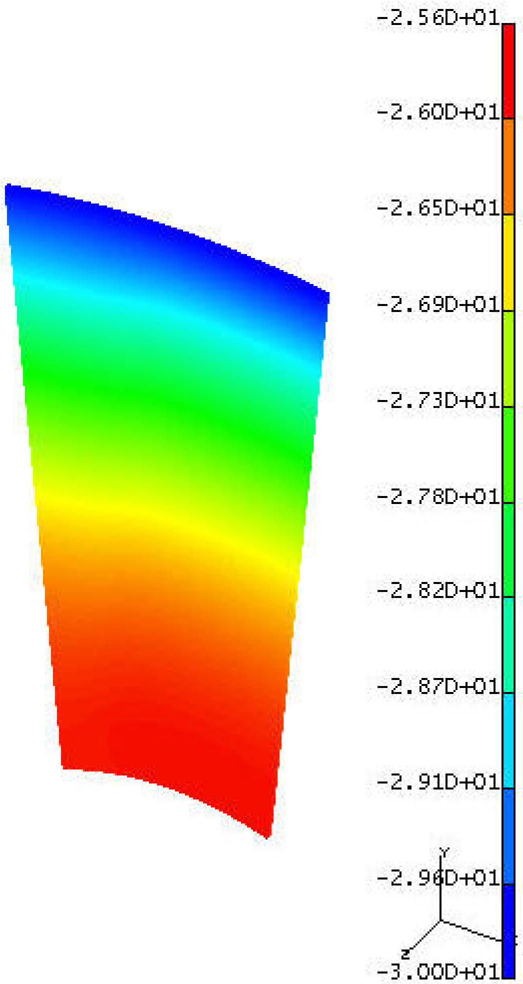
Front Side

Back Side

0.06 cf + 0.88 TPG + 0.06 cf Blade
150% heat load, 7.3W per blade;
sensor: 0.6 W; ROC: 6.7 W

Configuration (2)
Heat sink on outer edge only
HDI glued next to the substrate



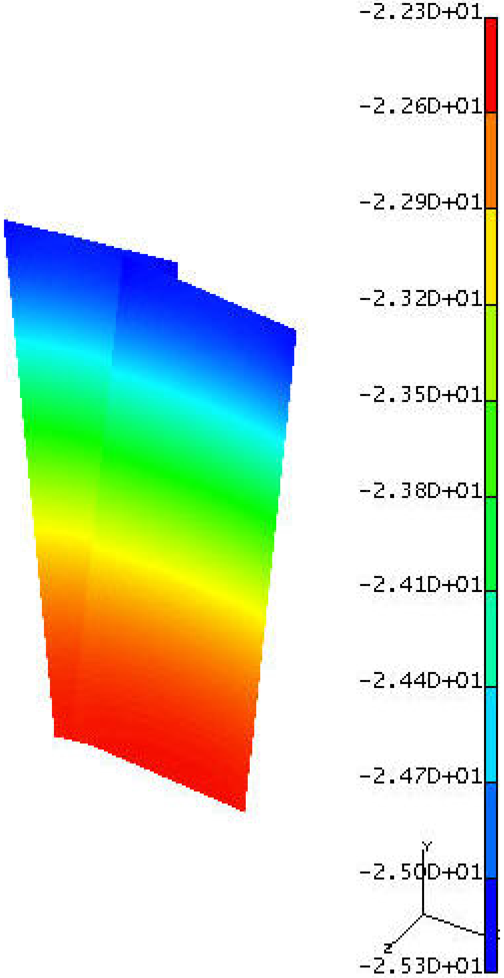


ΔT = 4.7C across CF
Max temp = -25.3C

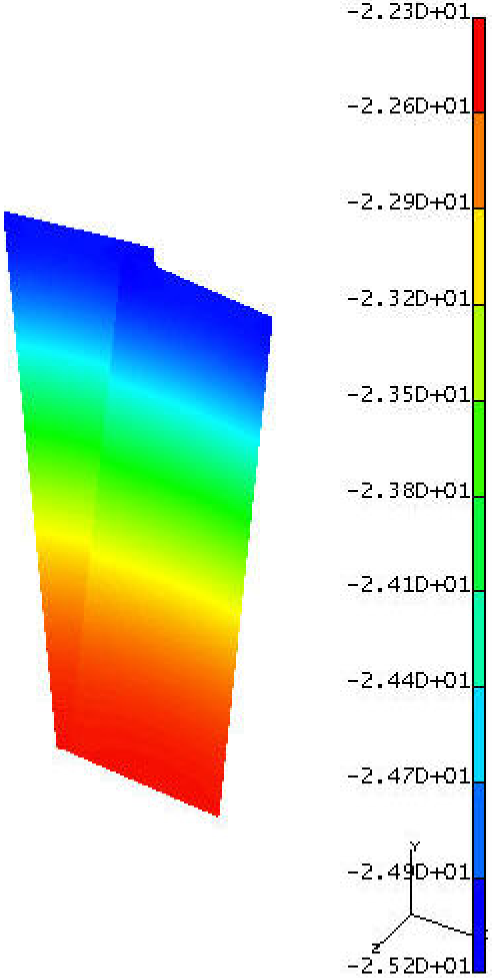
ΔT = 4.4C across TPG
Max temp = -25.6C

<u>0.06 cf + 0.88 TPG + 0.06 cf Blade</u>
150% heat load, 7.3W per blade;
sensor: 0.6 W; ROC: 6.7 W

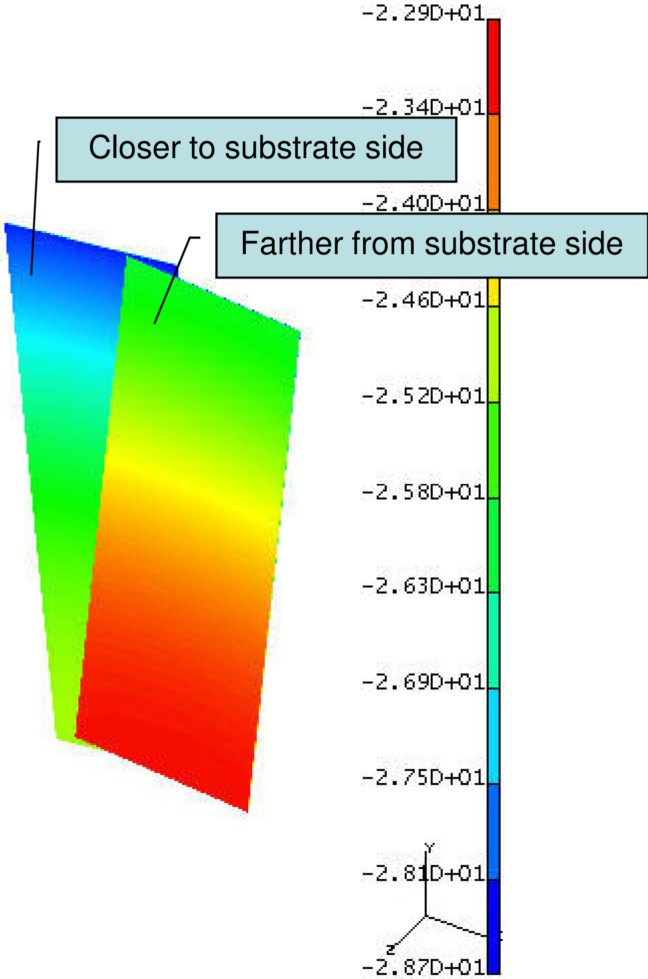
Configuration (2)
Heat sink on outer edge only
HDI glued next to the substrate



ΔT = 3.0C across ROC
Max temp = -22.3C



ΔT = 2.9C across sensor
Max temp = -22.3C



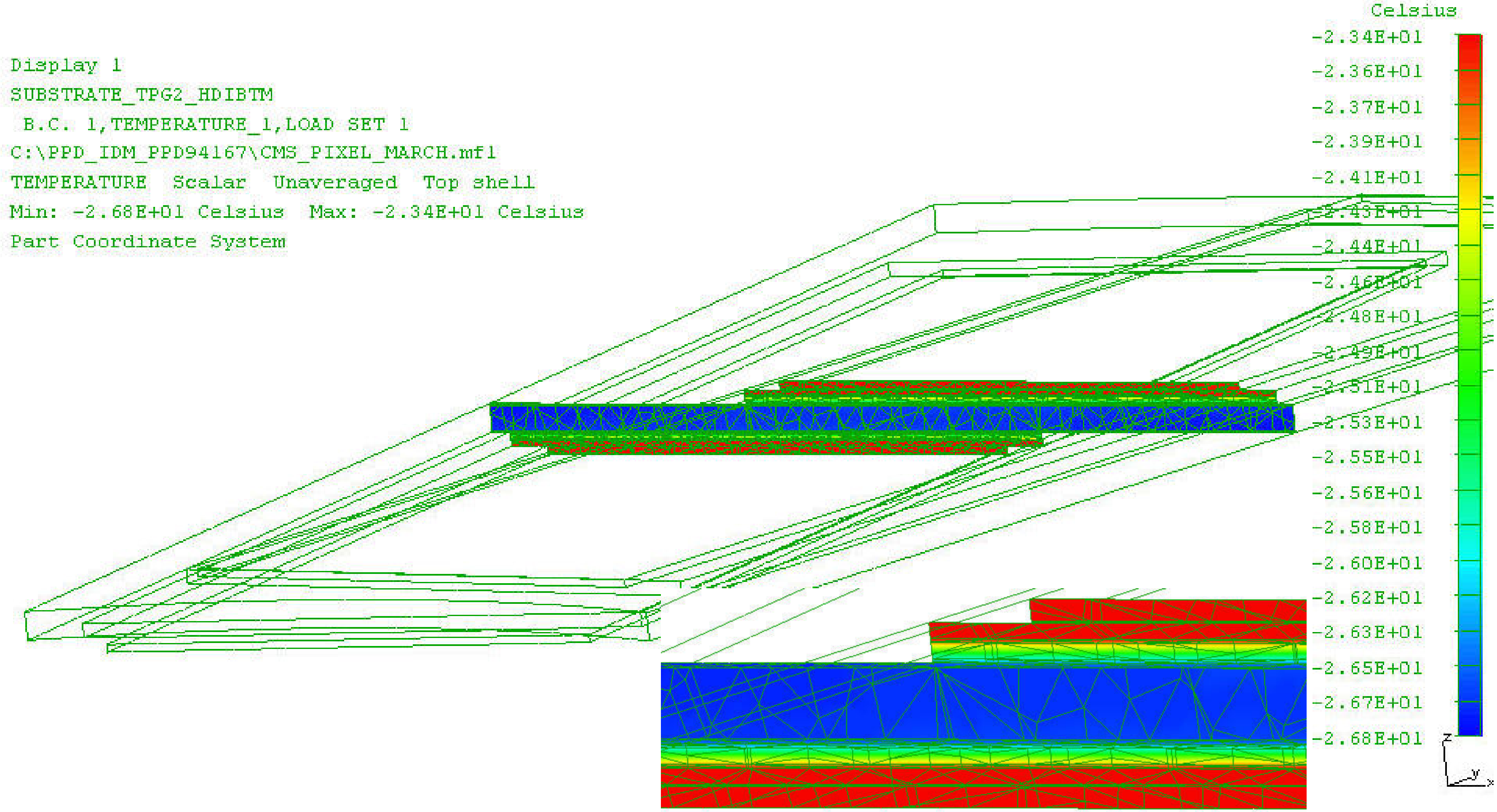
Closer to substrate side

Farther from substrate side

ΔT = 5.8C across HDI
Max temp = -22.9C

0.06 cf + 0.88 TPG + 0.06 cf Blade
150% heat load, 7.3W per blade;
sensor: 0.6 W; ROC: 6.7 W

Configuration (2)
Heat sink on outer edge only
HDI glued next to the substrate



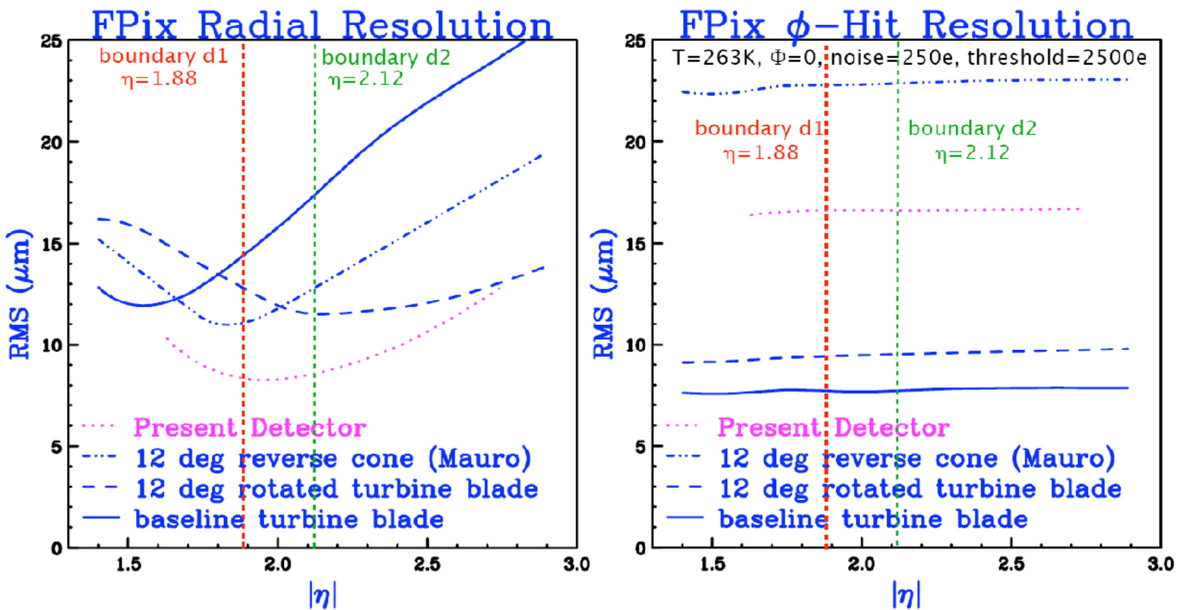
```
Display 1
SUBSTRATE_TPG2_HDIBTM
 B.C. 1,TEMPERATURE_1,LOAD SET 1
C:\PPD_IDM_PPD94167\CMS_PIXEL_MARCH.mfl
TEMPERATURE  Scalar  Unaveraged  Top shell
Min: -2.68E+01 Celsius  Max: -2.34E+01 Celsius
Part Coordinate System
```

$\Delta T = 3.4C$
across the mid-cut section

Thermal Pyrolytic Graphite (TPG)

- A unique form of pyrolytic graphite
- Made by the decomposition of a hydrocarbon gas within vacuum furnace
- Exceptionally high thermal conductivity (in-plane k = up to 1700 W/m-K, out-of-plane k = 10W/m-K at room temperature)
- Low CTE (in-plane = -1 ppm/C, out-of-plane = 25 ppm/C)
- Low density = 2.26 g/cc
- Long X0 = 18.9 cm (X0*k = 321 W/K vs 51 W/K of Be)
- Only available in rigid but brittle sheet, non-bendable.
- Friable, needs encapsulation; carbon fiber composite is chosen for needed rigidity within material budget constraint.

- Vendors:
  - Momentive Performance Materials (http://advceramics.com/)
  - MiNTEQ (http://pyrographite.com/)



Proposed FPix geometries were studied by Morris Swartz (JHU) using the detailed Pixelav simulation currently used to generate reconstruction templates. Five geometries were studied: the current design, the Rotated Vane, 20° and 30° ‘Fresnel Lens’ (with castellated modules) layouts, and a 12° inverted cone array of Rotated Vanes.

The Rotated Vane design (labeled ‘baseline turbine blade’ in the above plots) has excellent azimuthal (phi) resolution (better by x2 compared to the current FPix detector); however, the radial resolution is worse for high eta.

The Fresnel Lens layouts perform worse compared to the current detector geometry.

Tilting the blades in the Inner Assemblies into inverted cones (labeled ‘12 deg rotated turbine blade’ above) improves the high-eta radial resolution and only slightly worsens the high-eta azimuthal resolution. The radial resolution curves break along the vertical dotted lines at the eta between the Outer and Inner Blade Assemblies.