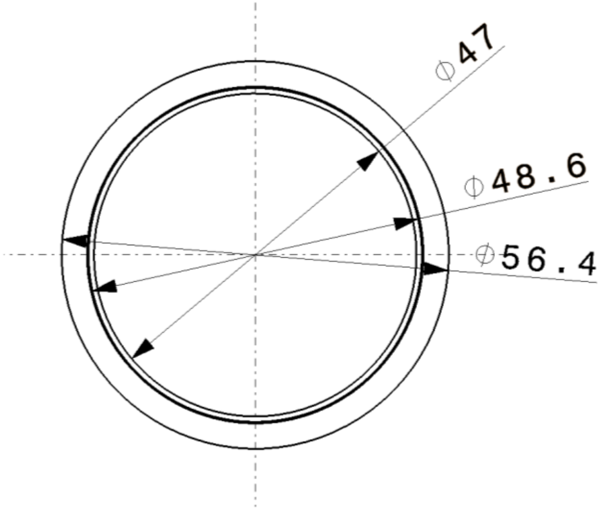
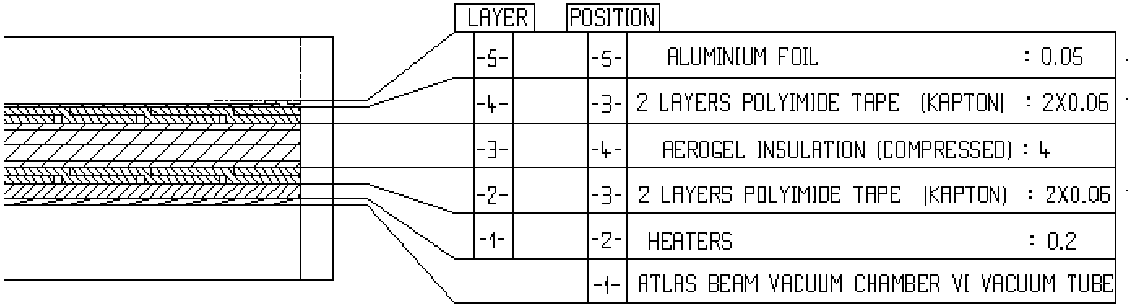
CFD thermal simulations
IBL with 47 mm i.d. beam pipe

Enrico Da Riva, Anne-Laure Lamure
CFD Team (EN/CV)

Geometry
and
material properties

Beam pipe geometry & materials

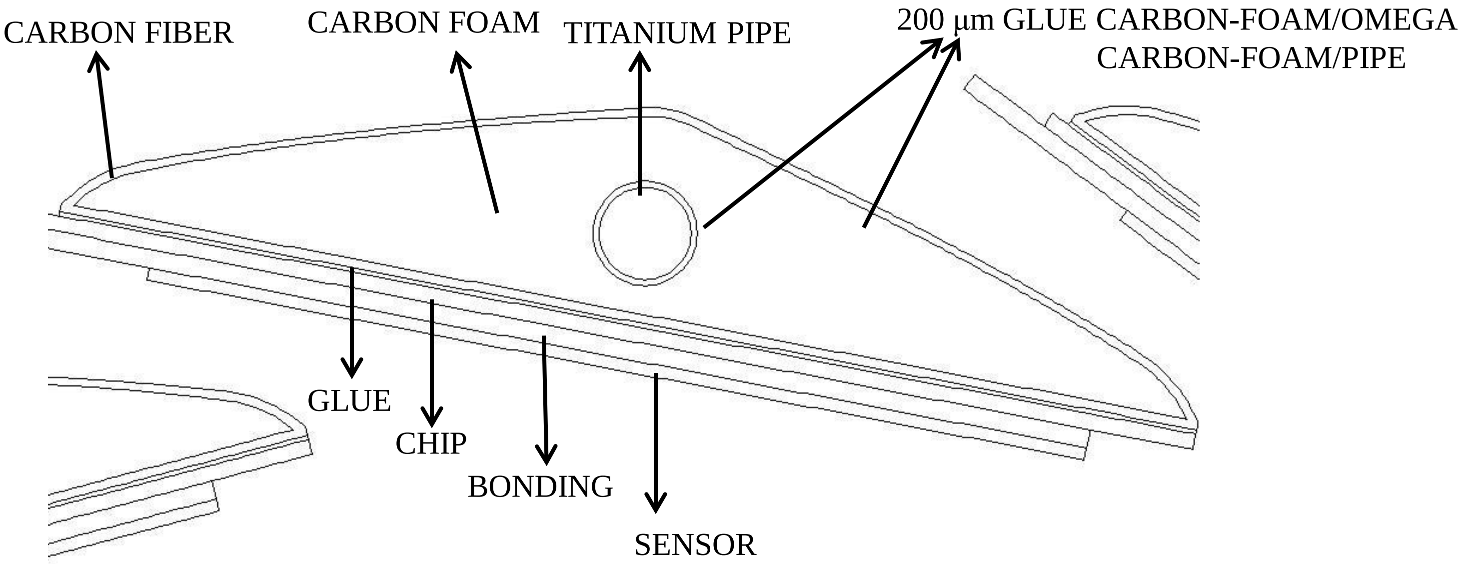




LAYER	POSITION	
-5-	-5-	ALUMINIUM FOIL : 0.05
-4-	-3-	2 LAYERS POLYIMIDE TAPE (KAPTON) : 2X0.06
-3-	-4-	AEROGEL INSULATION (COMPRESSED) : 4
-2-	-3-	2 LAYERS POLYIMIDE TAPE (KAPTON) : 2X0.06
-1-	-2-	HEATERS : 0.2
	-1-	ATLAS BEAM VACUUM CHAMBER VI VACUUM TUBE

- ❑ Insulation layer (48.6 mm < D < 56.4 mm) modeled in the CFD simulations.
- ❑ Equivalent thermal conductivity 0.0156 W $m^{-1}K^{-1}$ (~ aerogel conductivity).
- ❑ Boundary conditions (250 °C for bake out) set at the outside of beryllium pipe.
- ❑ Aluminum foil emissivity = 0.05 (slightly overestimated).

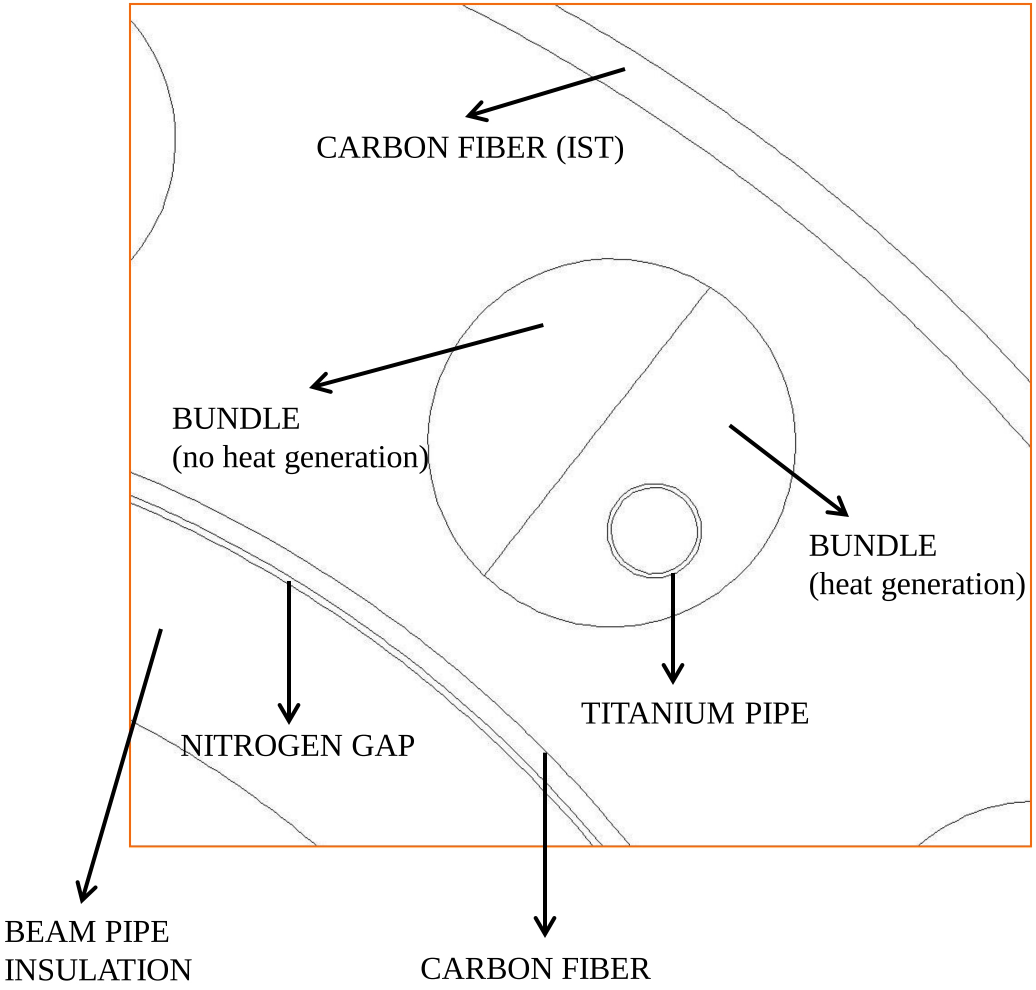
IBL geometry & materials



MATERIALS		
	Thickness [µm]	**Conductivity [W m^{-1} K^{-1}]**
OMEGA (Carbon Fiber)	150	2.2
CARBON FOAM	-	25
TITANIUM PIPE (i.d. 1.5 mm)	100	7.2
GLUE	70	1
CHIP (silicon)	250	148
BONDING	300	6.32
SENSOR (silicon)	200	148

- ☐ Perfect thermal contact between different layers in the CFD simulations.

Services geometry & materials



CARBON FIBER (IST)

BUNDLE
(no heat generation)

BUNDLE
(heat generation)

TITANIUM PIPE

NITROGEN GAP

BEAM PIPE
INSULATION

CARBON FIBER

MATERIALS	
	Conductivity [W m^{-1} K^{-1}]
CARBON FIBER	2.2
TITANIUM PIPE (i.d. 1 mm)	7.2
BEAM PIPE INSULATION	0.0156
BUNDLE	0.5 – 0.02

- Difficult estimation of the bundle equivalent thermal conductivity.
- Two cases considered: full polyimide (k = 0.5 W m^{-1}K^{-1}) and *very worst case scenario*: solid with thermal properties of nitrogen (k = 0.02 W m^{-1}K^{-1}).

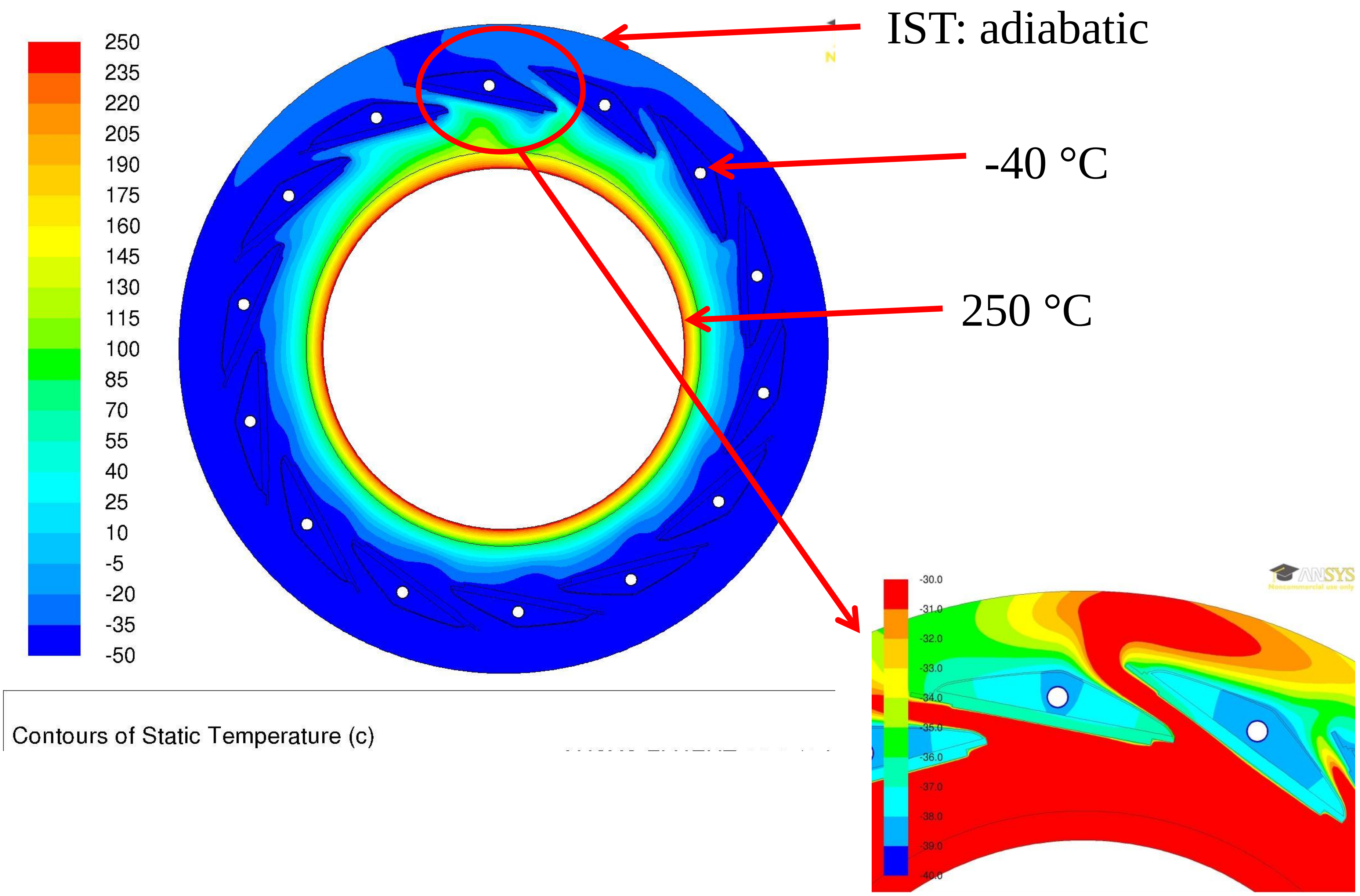
Simulation cases

1. **IBL-only cross section, bake-out**
2. **IBL-only cross section, nominal operation**
3. **Services-only cross section, bake-out**
4. **Services-only cross section, nominal operation**

Settings

- ☐ Nitrogen flow rate = 0 kg/s.
- ☐ Natural convection of nitrogen taken into account.
- ☐ Radiative heat transfer taken into account (emissivity 0.05 for beam pipe, 1 for other surfaces).
- ☐ Dependence of nitrogen properties on temperature taken into account.
- ☐ Laminar natural convection flow.
- ☐ Geometry of B-layers not available. IST set as adiabatic.

1. IBL-only, bake-out (temperature)



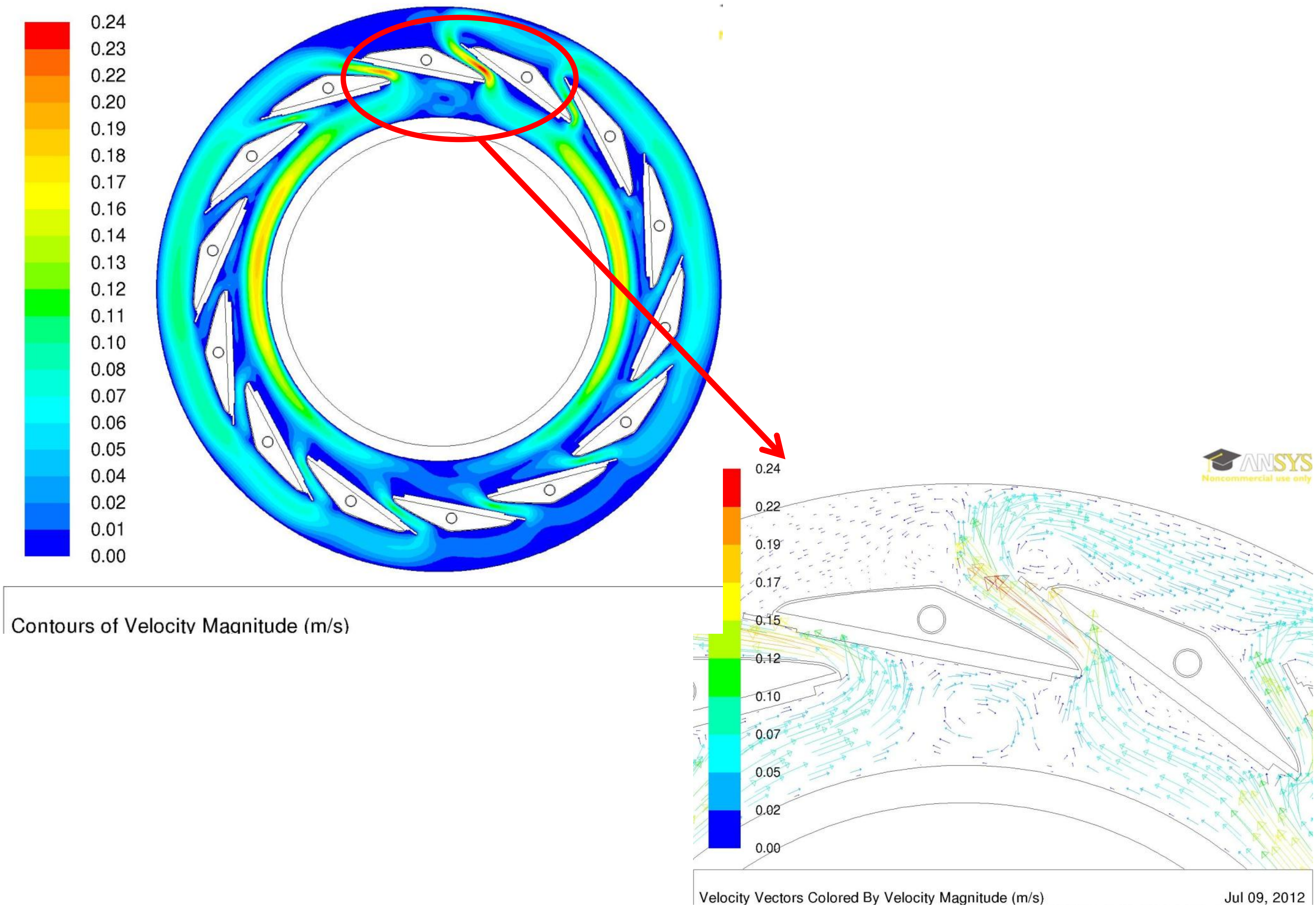
IST: adiabatic

-40 °C

250 °C

Contours of Static Temperature (c)

1. IBL-only, bake-out (velocity)

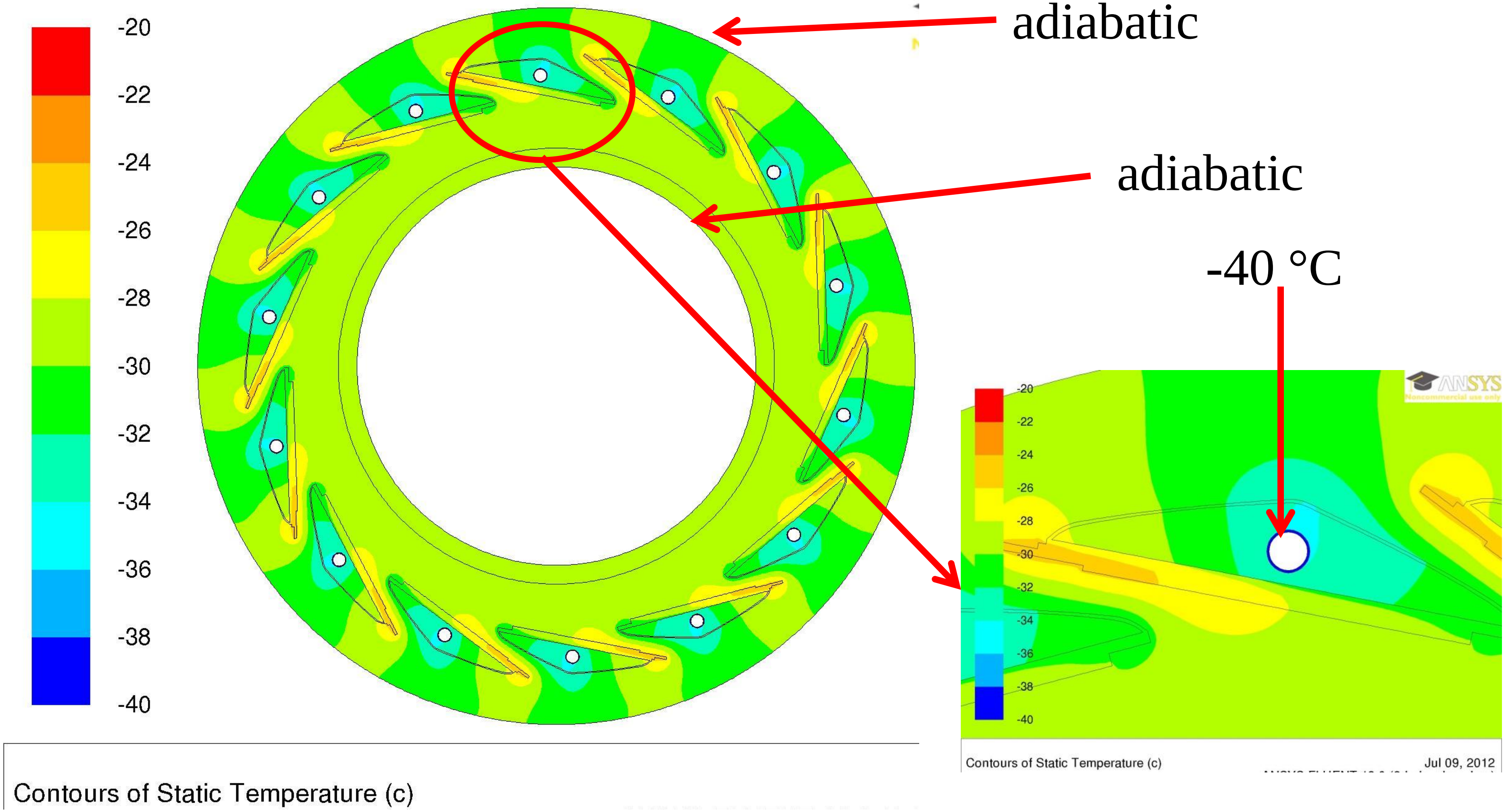


Contours of Velocity Magnitude (m/s)

Velocity Vectors Colored By Velocity Magnitude (m/s)

Jul 09, 2012

2. IBL-only, nominal operation (temperature)



adiabatic

adiabatic

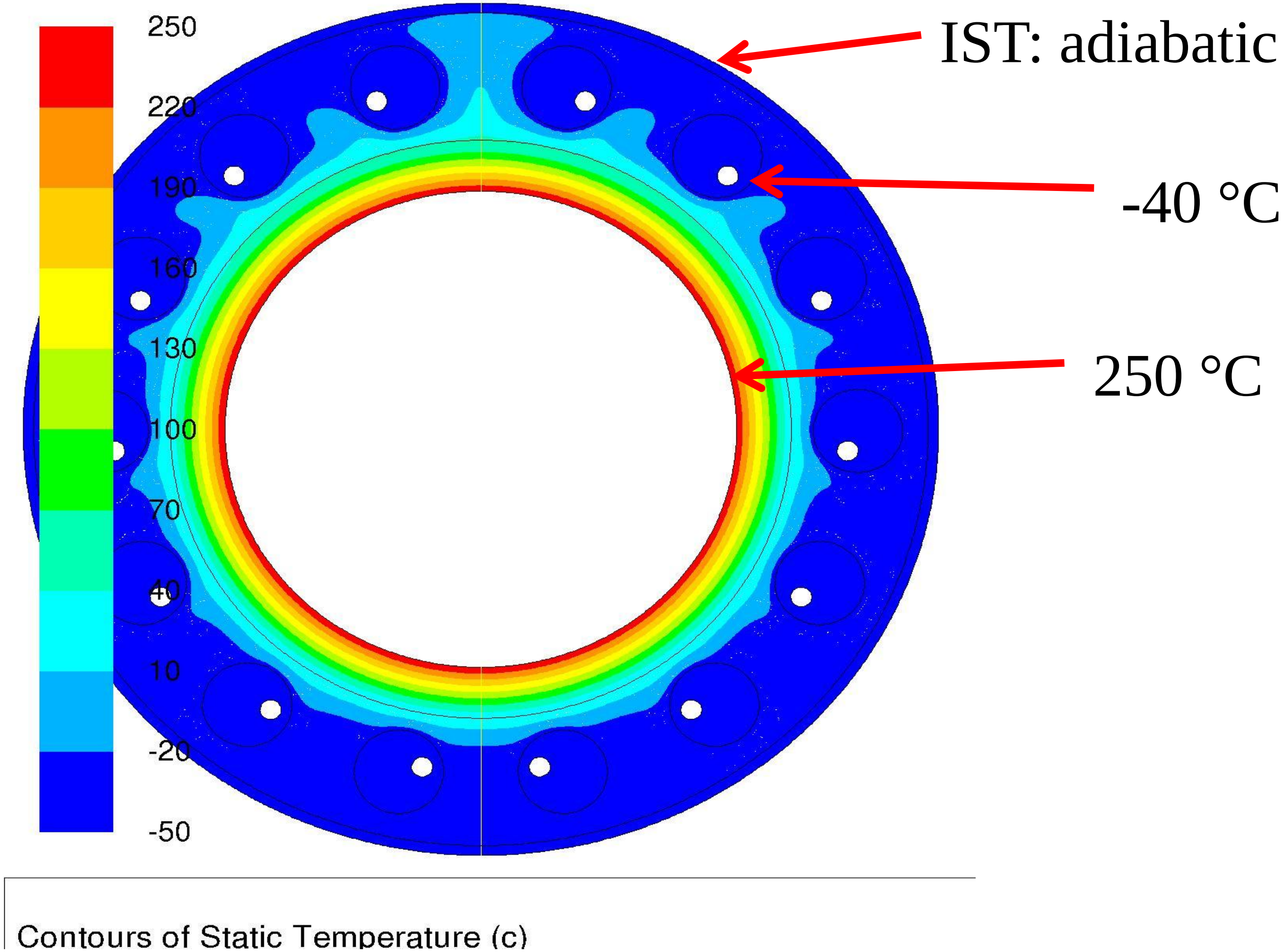
-40 °C

Contours of Static Temperature (c)

- 0.5 W cm^{-2} on the chip, 0.35 W cm^{-2} on the sensor (total ~100 W per stave).

3. Services, bake-out

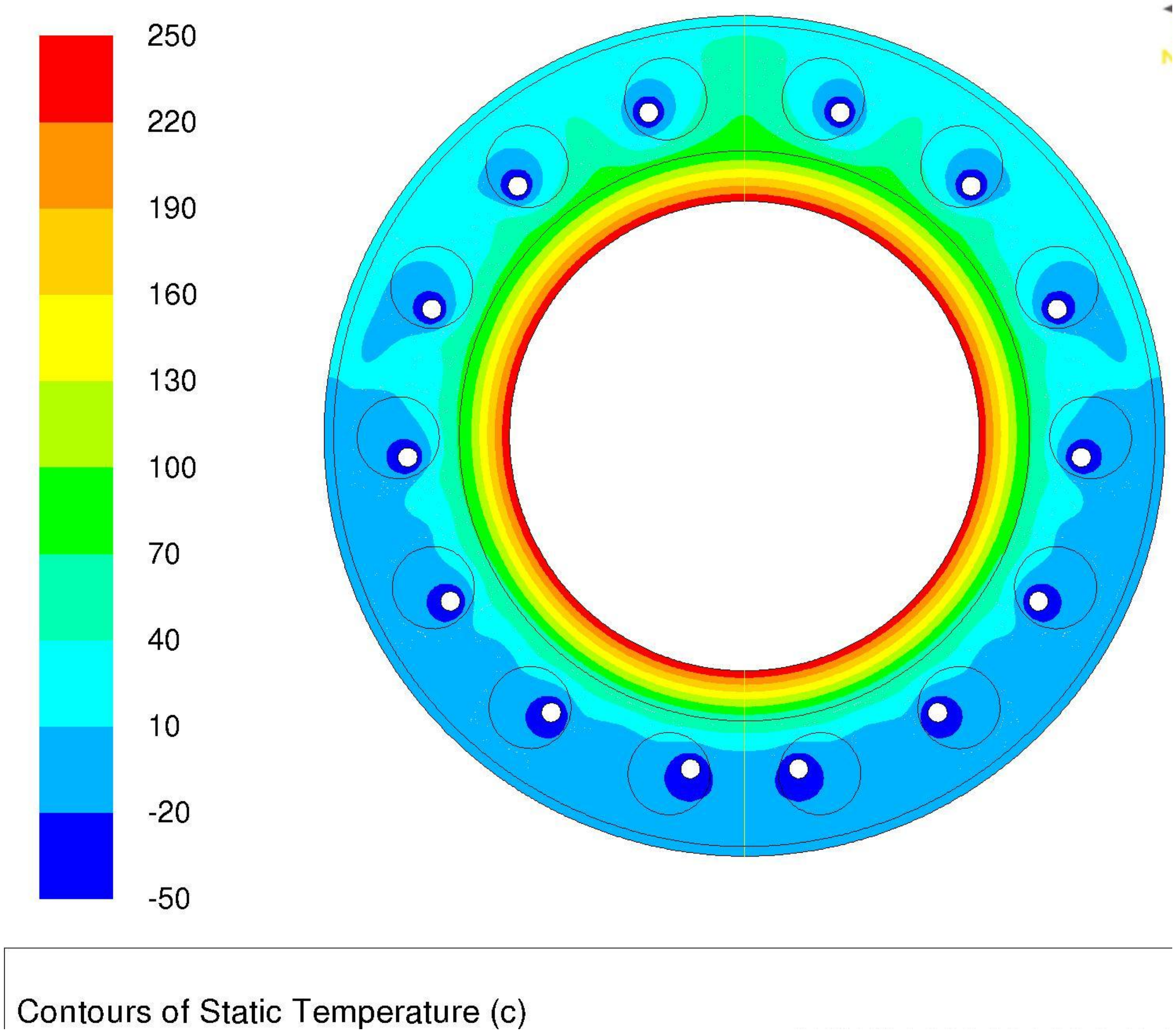
3A) Bundle equivalent conductivity *k* = 0.5 W m^{-1} K^{-1}



Contours of Static Temperature (c)

3. Services, bake-out

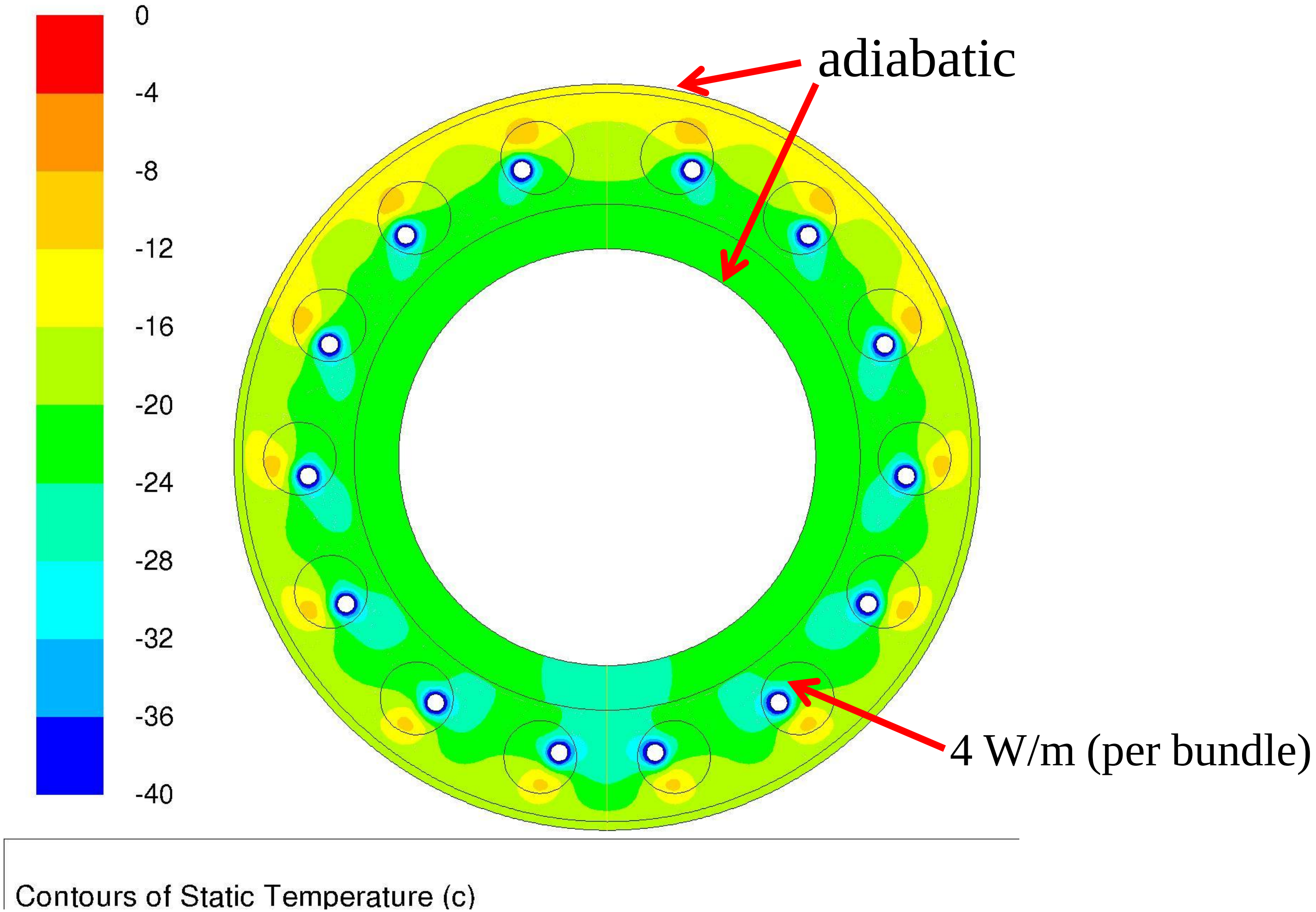
3B) WORST CASE SCENARIO:
Bundle equivalent conductivity $k = 0.025\ \mathrm{W\ m^{-1}\ K^{-1}}$



Contours of Static Temperature (c)

4. Services, nominal operation

WORST CASE SCENARIO: Bundle equivalent conductivity k = 0.025 W m^{-1} K^{-1}



Contours of Static Temperature (c)

Summary table

Simulation	T. max (sensor or bundle) [°C]	Heat from beam pipe [W m^{-1}]	Heat flux on cooling pipe inner surface [W m^{-2}]
IBL, bake-out	-36	167	2532
IBL, nominal operation	-25	0	31850
Services, bake out	-31/48	59/49	1355/1117
Services, nominal operation	<8	0	640

- ☐ According to the present results, no cooling problem is expected during the bake-out.

Estimation of actual titanium temperature

- ☐ In the simulations, the temperature of inner surface of the titanium pipe is set as the CO_2 saturation temperature (i.e. -40°C).
- ☐ A rough estimation of the CO_2 heat transfer coefficient and the actual saturation-to-wall temperature difference has been obtained by means of the Cooper correlation (for pool boiling).

Simulation	Heat flux on cooling pipe inner surface [W m^{-2}]	HTC [W m^{-2} K^{-1}]	Refrigerant/wall ΔT [K]
IBL bake-out	2532	1400	~2
IBL nominal operation	31850	7400	~4
Services bake out	1355/1117	800	~1.5
Services nominal operation	640	500	~1

Thank you