Module Design and Finite Element Calculations

Günter Eckerlin, Jens Hansen,
Carsten Muhl, Andreas Mussgiller,
Jan Olzem

CEC Meeting
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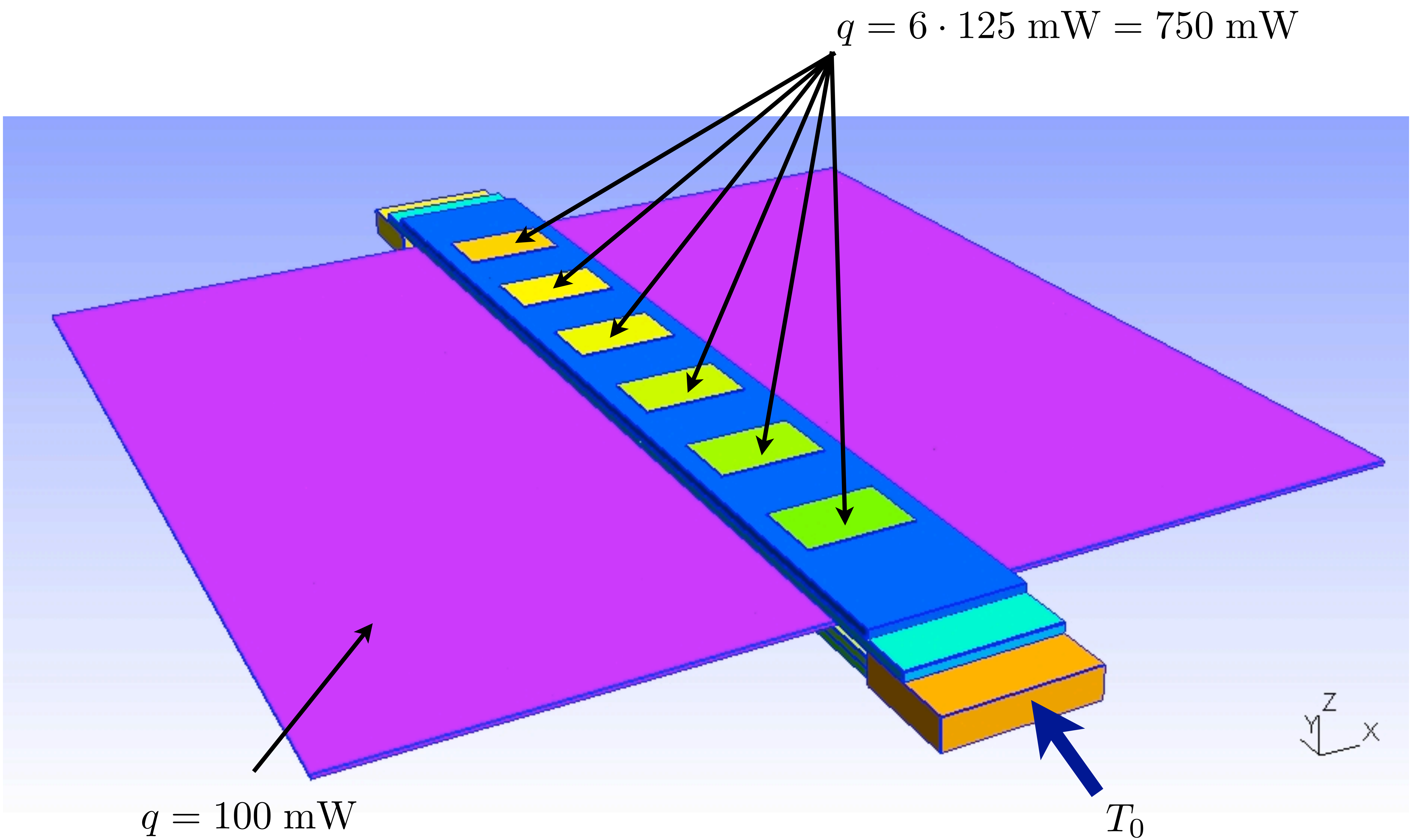
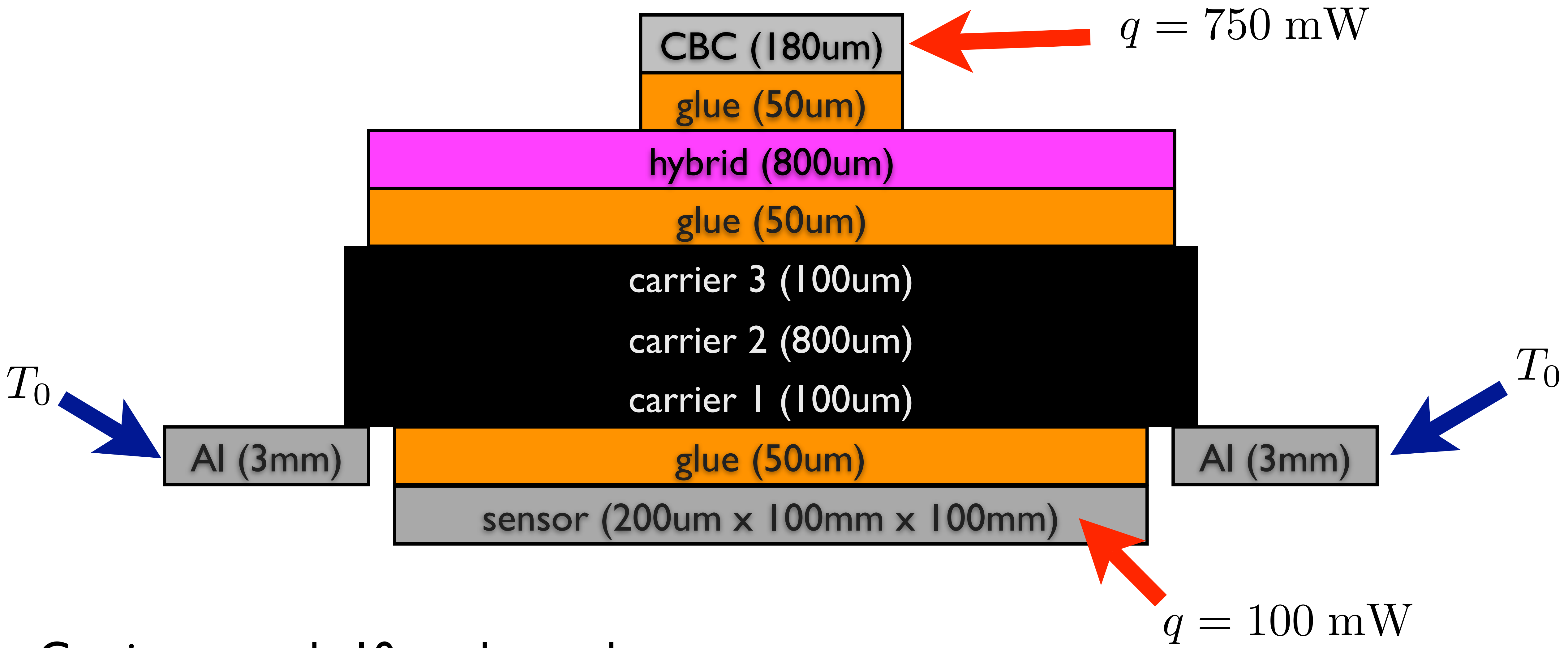
Outline

- Module with long strixel
  - Comparison to UCSB FE calculations
  - Refined results for standard design
  - Design with long cooling contact
  - Thermal & material budget comparisons
- Module with short strixel
  - Standard design
  - Design with long cooling contact
  - Thermal comparison
- Summary
- Outlook

Standard Design

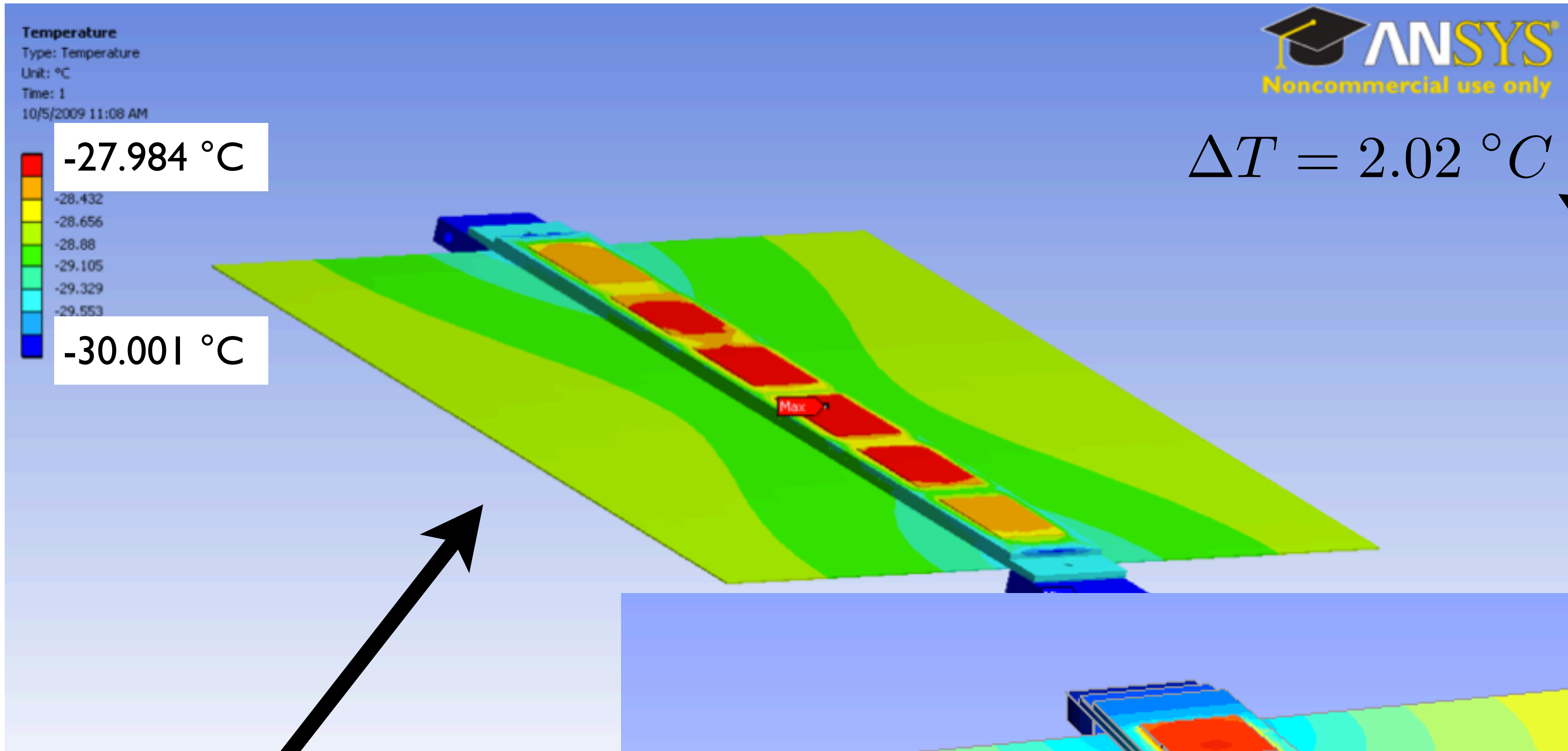


Standard Design continued



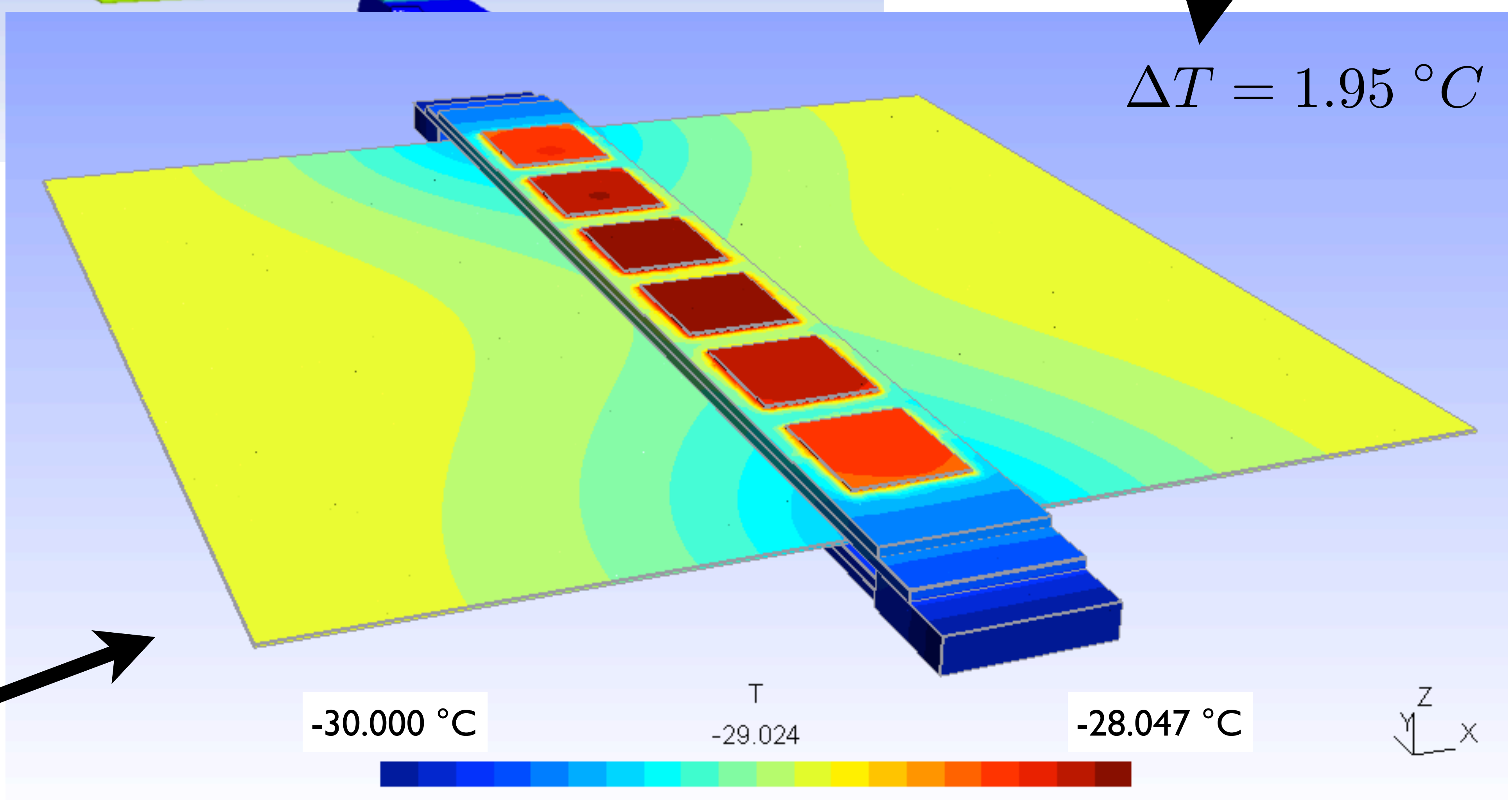
- Carrier extends 10mm beyond sensor
- Carrier split into 3 logical parts to simplify simulation of encapsulated TPG
- Hybrid extends 5mm beyond sensor
- Overlap between cooling block and Carrier is 5mm
- CBC power distributed over 6 chips in 1 row on hybrid (10mm x 12mm each)
- Side surfaces of cooling blocks kept at reference temperature
- Implementation similar to FE Model by UCSB (see talk at TUPO 14/10/09)

Standard Design Comparison - Overall Temperature



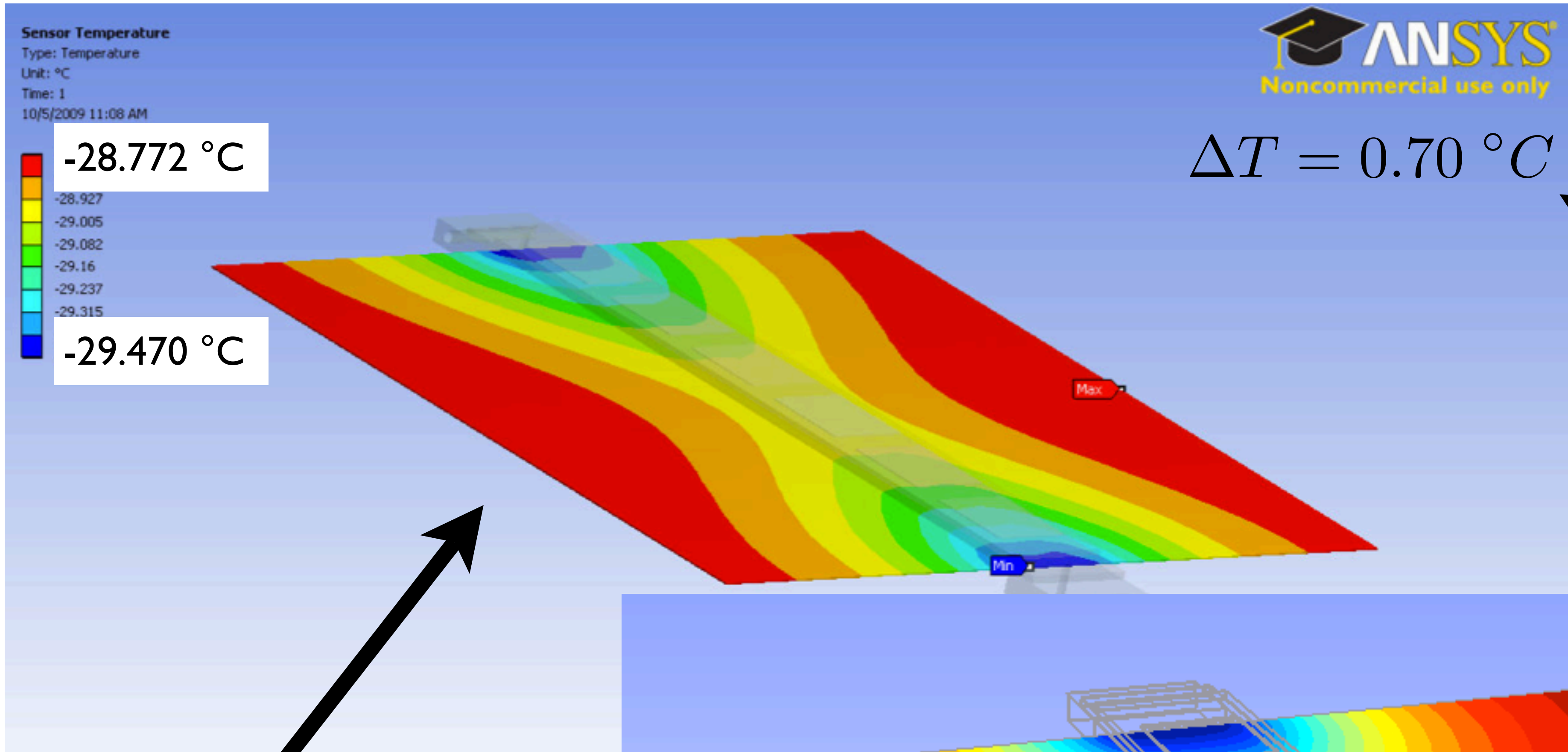
Temperature difference between cooling contact and warmest node

UCSB



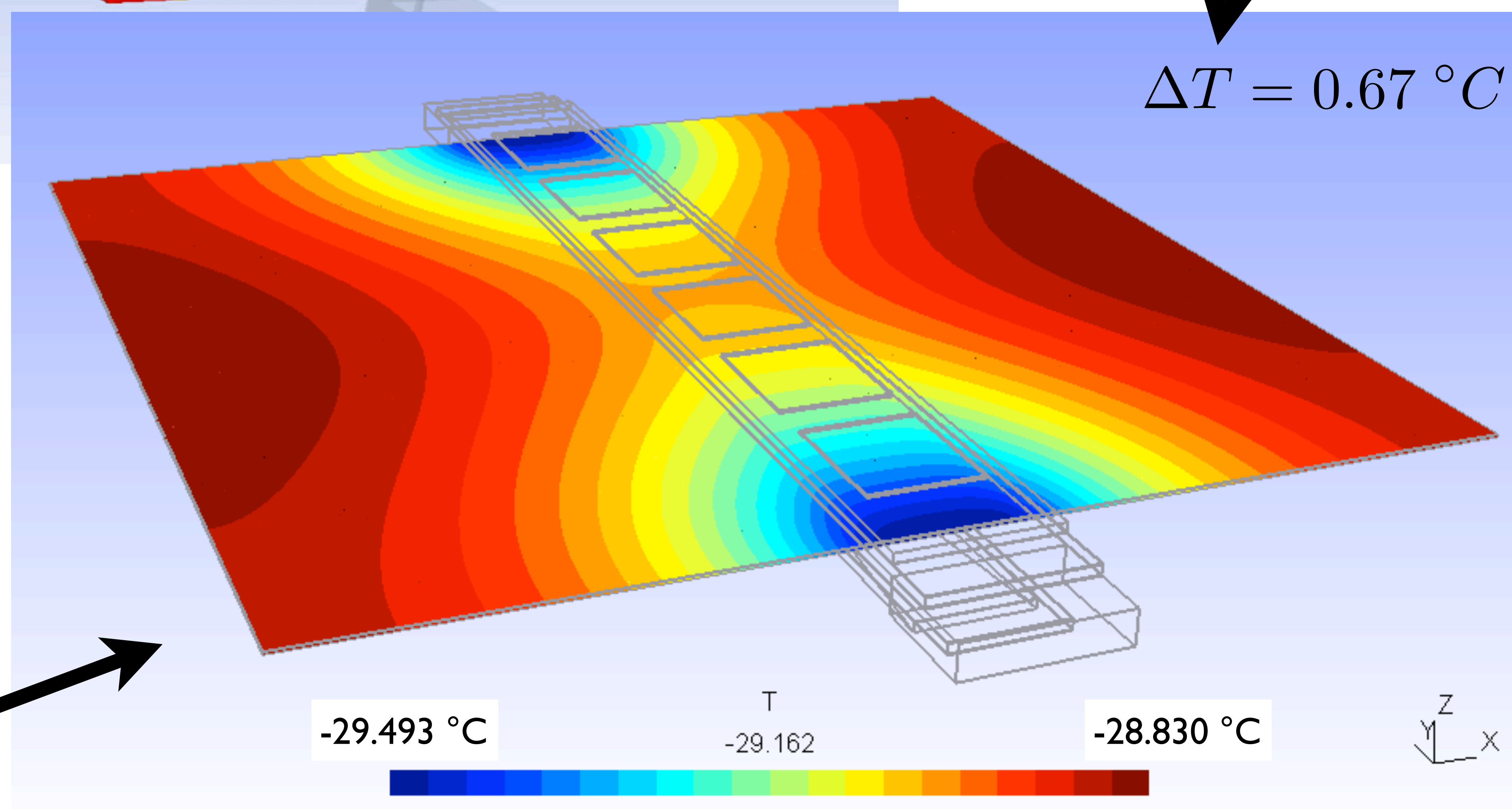
DESY

Standard Design Comparison - Sensor Temperature



Temperature difference between coldest and warmest node on sensor

UCSB



DESY

Standard Design Comparison - Conclusions

- Results from UCSB (ANSYS) and DESY (getDP) FE calculations are very similar
- Differences might be related to
  - modelling of TPG strip
  - different thicknesses of glue layers / additional glue layers

- A more realistic FE calculation needs to take into account
  - Inhomogeneity of Hybrid thermal conductivity due to signal layers
  - Heat transfer from CO_2 to cooling pipe
  - „Dynamic“ sensor power

Thermal Conductivity of Hybrid

- 800 um total thickness
- 12 um thick copper layers
  - 4 layers with full coverage (power and ground)
  - 8 layers with 15% coverage (signal)
- 800 um - 12 * 12 um = 656 um (thickness of G10)
- Vias are not taken into account

$$\lambda_{in-plane}^{Hybrid} = \frac{656}{800} \cdot \lambda_{in-plane}^{G10} + \frac{4 \cdot 12}{800} \lambda_{in-plane}^{Copper} + \frac{8 \cdot 12}{800} \left(0.15 \cdot \lambda_{in-plane}^{Copper} + 0.85 \cdot \lambda_{in-plane}^{G10}\right)$$

$$= \frac{656}{800} \cdot 0.3 \text{ W/mK} + \frac{4 \cdot 12}{800} 391 \text{ W/mK} + \frac{8 \cdot 12}{800} (0.15 \cdot 391 \text{ W/mK} + 0.85 \cdot 0.3 \text{ W/mK})$$

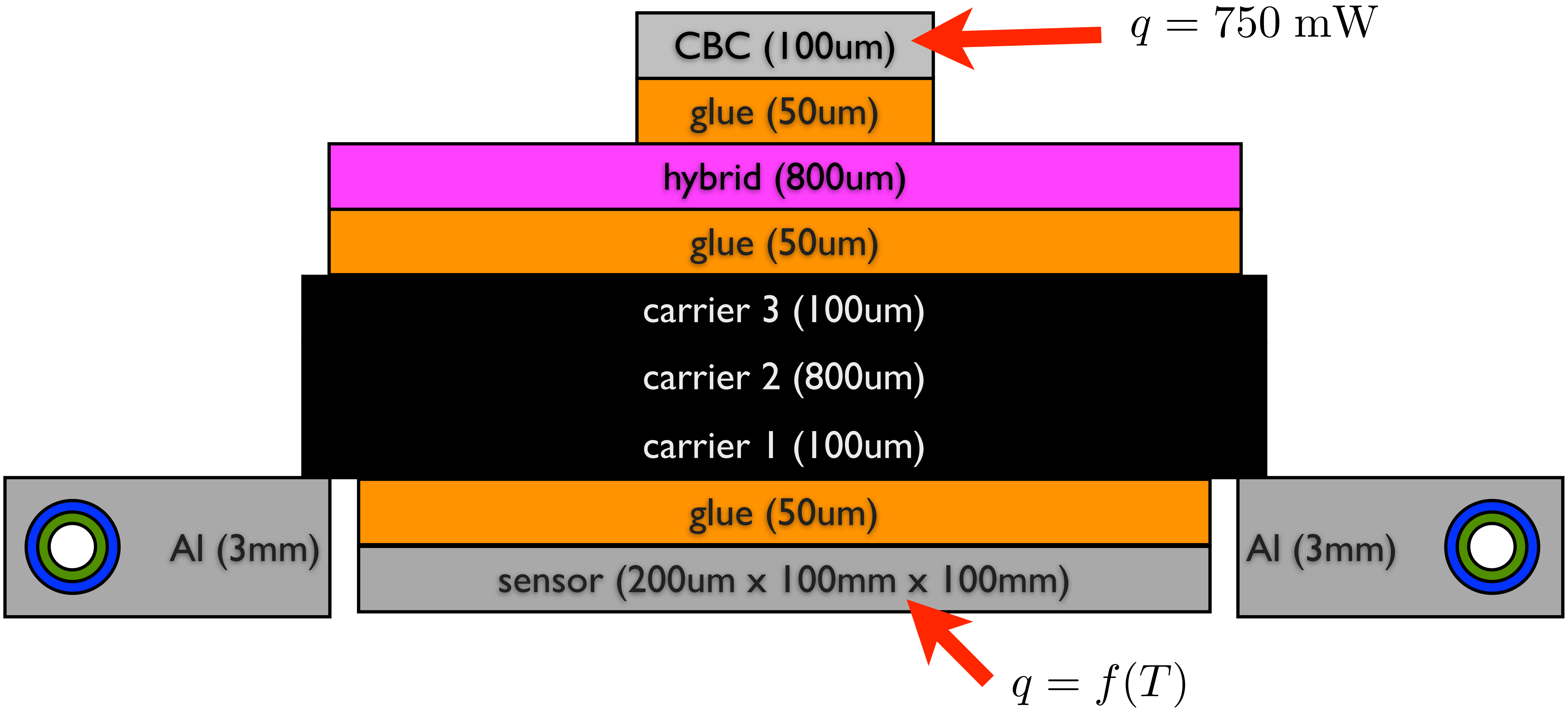
$$= 30.8 \text{ W/mK}$$

$$\lambda_{out-of-plane}^{Hybrid} = \frac{1}{\frac{\frac{656}{800}}{\lambda_{out-of-plane}^{G10}} + \frac{\frac{4 \cdot 12}{800}}{\lambda_{out-of-plane}^{Copper}} + \frac{\frac{8 \cdot 12}{800}}{\left(0.15 \cdot \lambda_{out-of-plane}^{Copper} + 0.85 \cdot \lambda_{out-of-plane}^{G10}\right)}}$$

$$= \frac{1}{\frac{\frac{656}{800}}{0.3 \text{ W/mK}} + \frac{\frac{4 \cdot 12}{800}}{391 \text{ W/mK}} + \frac{\frac{8 \cdot 12}{800}}{(0.15 \cdot 391 \text{ W/mK} + 0.85 \cdot 0.3 \text{ W/mK})}} = 0.37 \text{ W/mK}$$

Original value: 0.76 W/mK (both in and out of plane)

Thermal Conductivity of Hybrid

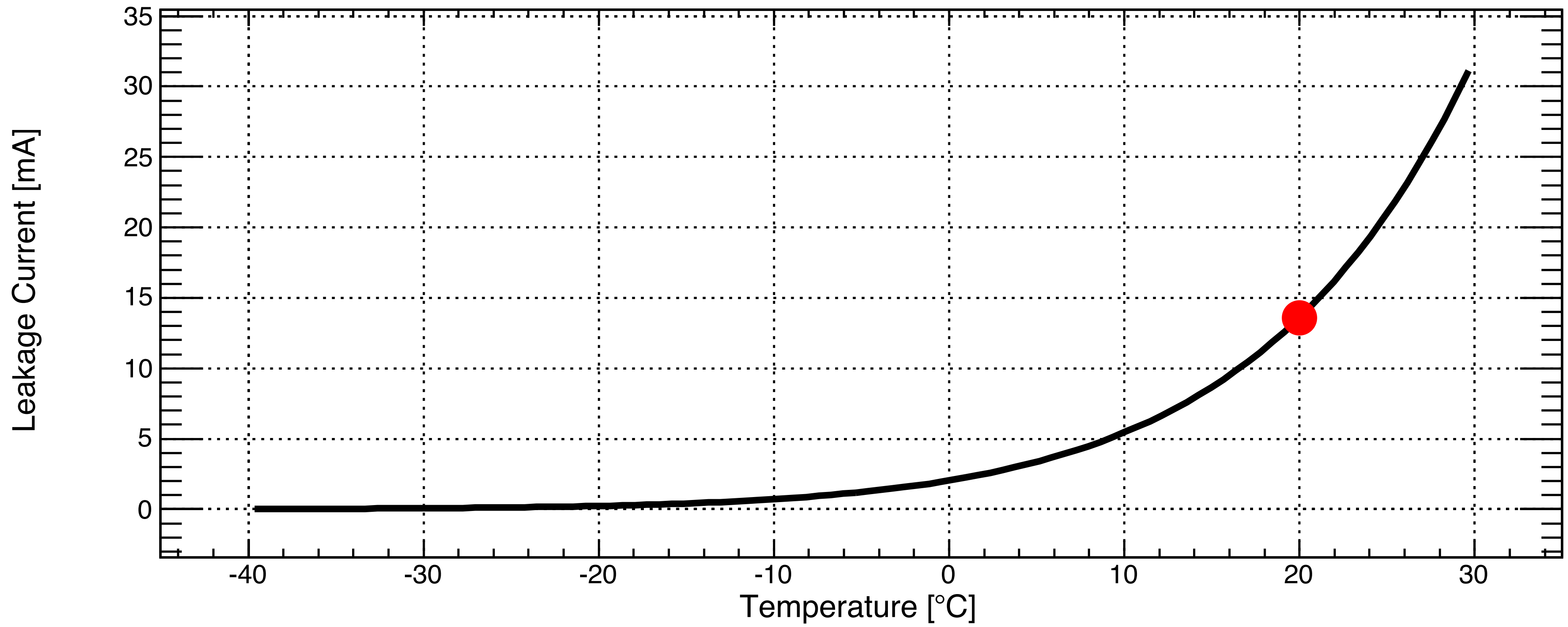


- Assume ideal heat transfer from **pipe** to Aluminum cooling block
- Inner surface of **CO2 layer** kept at reference temperature
- Heat transfer from pipe to CO2 modelled by 200µm thick layer with effective thermal conductivity:

$$\lambda = h \cdot t = 5000\ \frac{W}{m^2 K} \cdot 200\ \mu\mathrm{m} = 1\ \frac{W}{mK}$$

„Dynamic“ Sensor Power

- Leakage current varies with temperature
- Non-constant temperature distribution on sensor results in a non-constant local leakage current
- Non-constant local leakage current result in a non-constant power density
- $I^{20^\circ C}_{\mathrm{leakage}} = \kappa \cdot \Phi \cdot V_{\mathrm{sensor}}$ with $\kappa = 4.0 \cdot 10^{-17}\ \frac{\mathrm{A}}{\mathrm{cm}}$
- $I^{20^\circ C}_{\mathrm{leakage}} = 13.6\ \mathrm{mA}$ for $\Phi = 1.7 \cdot 10^{14}/\mathrm{cm}^2$ and $V_{\mathrm{sensor}} = 100\ \mathrm{cm}^2 \times 200\ \mu\mathrm{m}$



- For each element in FE calculation power density is calculated from temperature of element
- Thermal runaway behavior can be studied

„Dynamic“ Sensor Power

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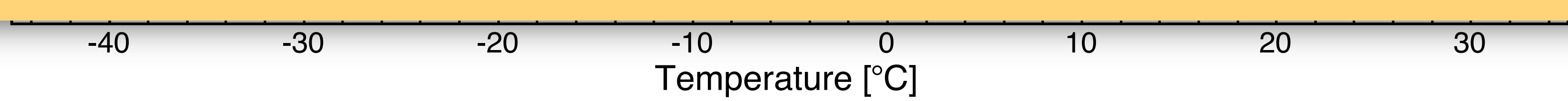
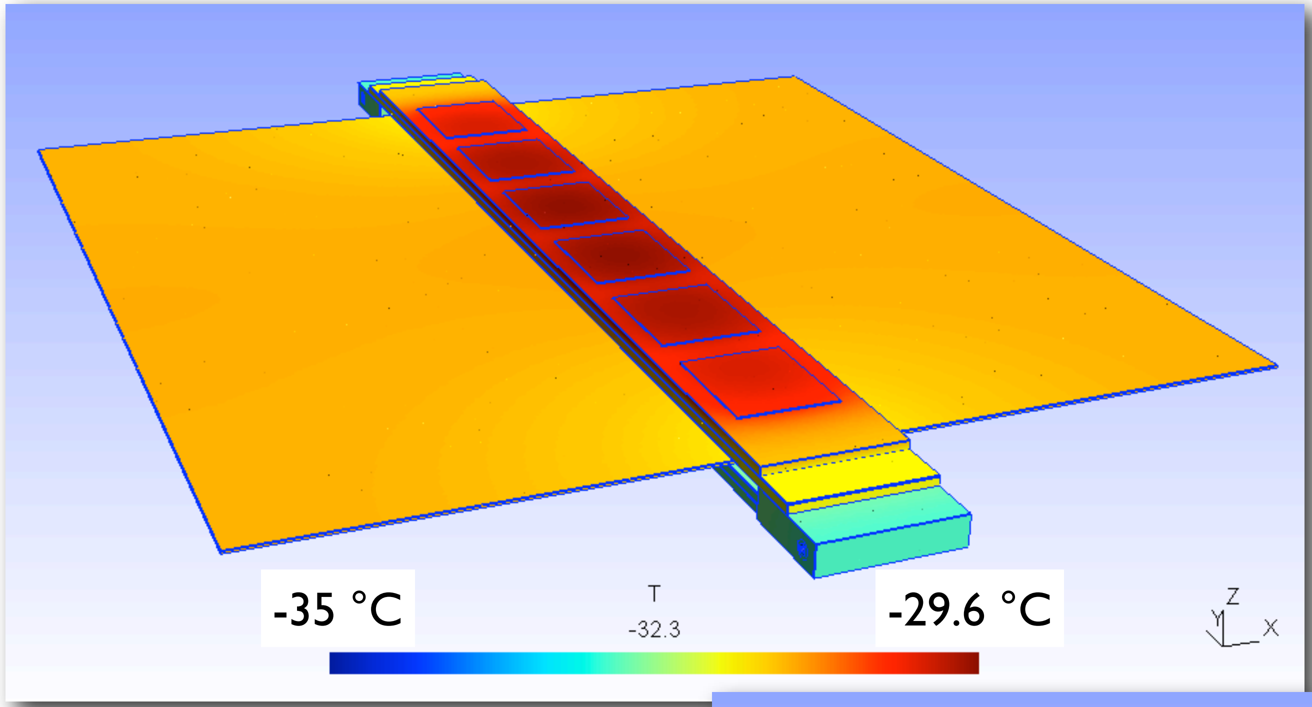
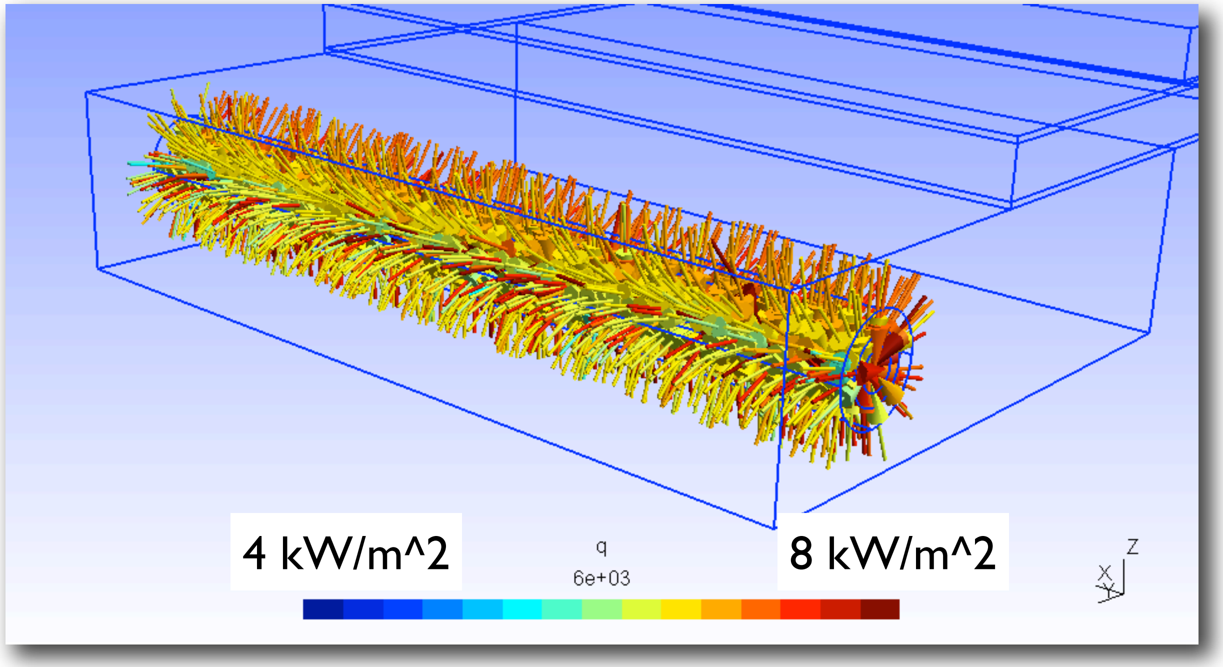


- Cool model to temperature of cooling contact
- „Switch“ on sensor and electronics
- In first iteration sensor power is calculated from temperature of cooling contact (uniform)
- Use temperature distribution on sensor after iteration as input for following iteration
- Number of iterations increases as one gets closer to thermal runaway

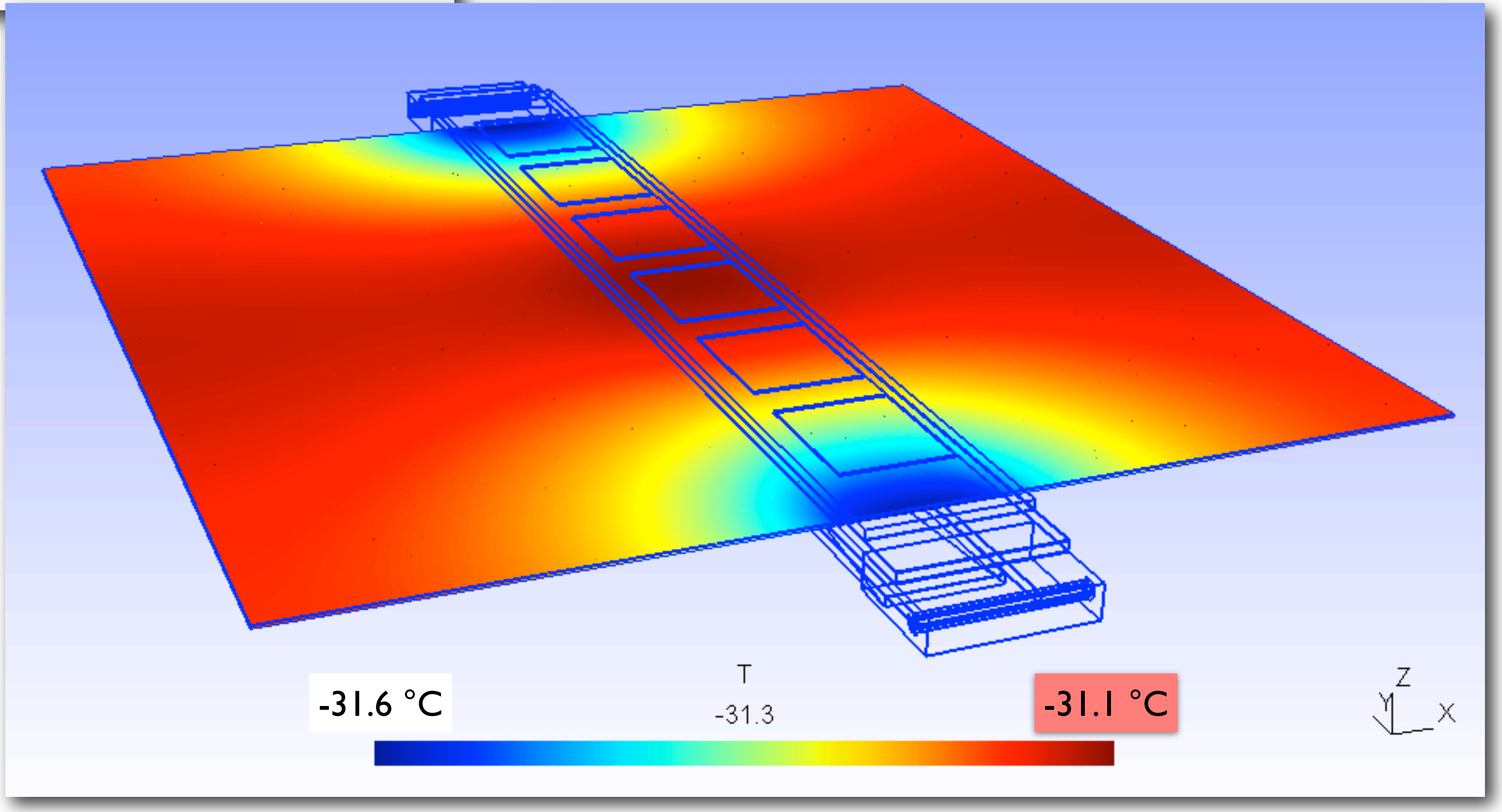
- For each element in FE calculation power density is calculated from temperature of element
- Thermal runaway behavior can be studied

Standard Design with long Strixel - Distributions

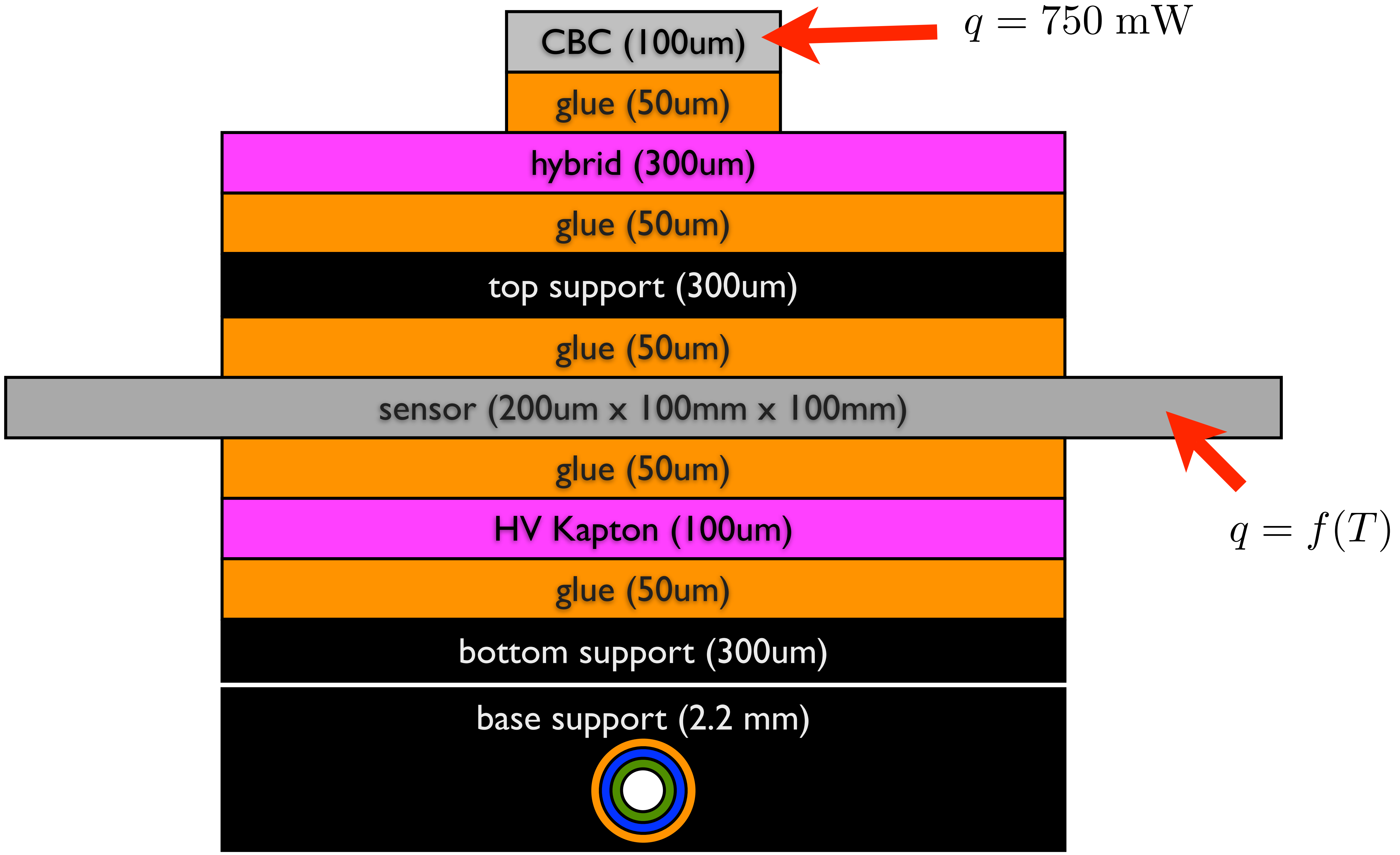




Fluence: 1.7e14
CBC power: 0.750 W
CO_2 temp: -35°C

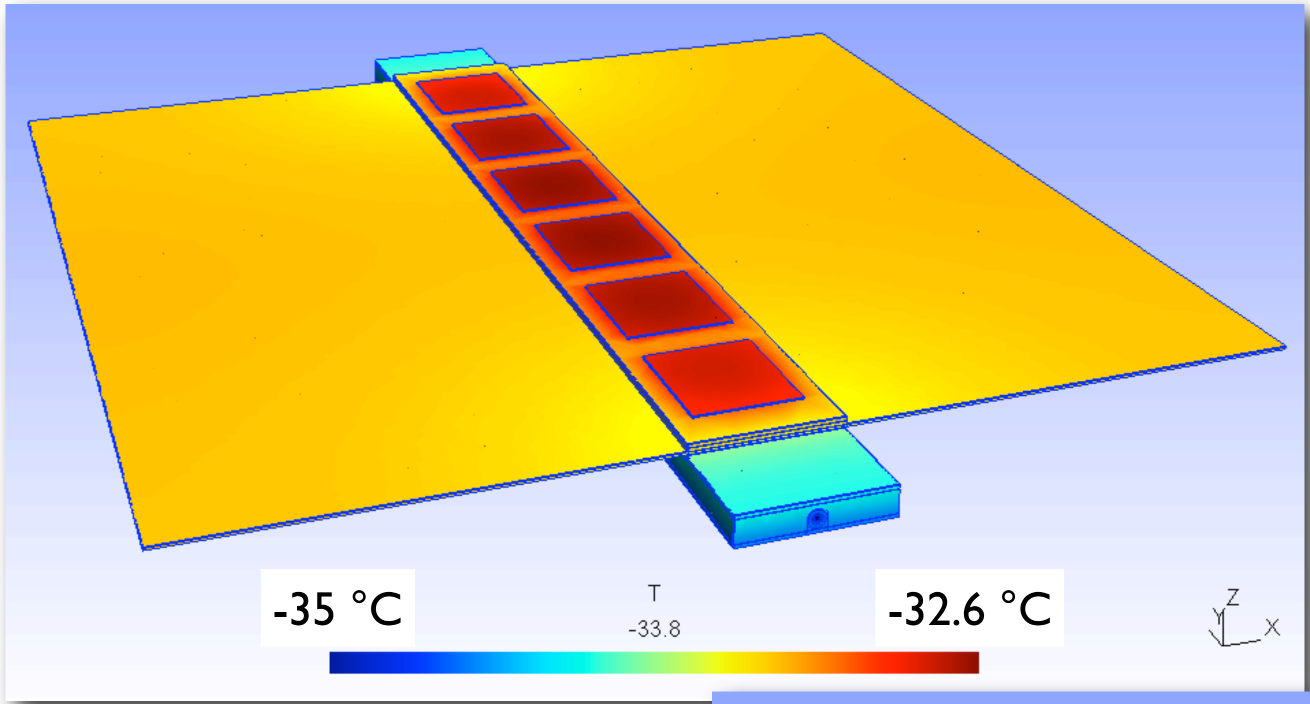


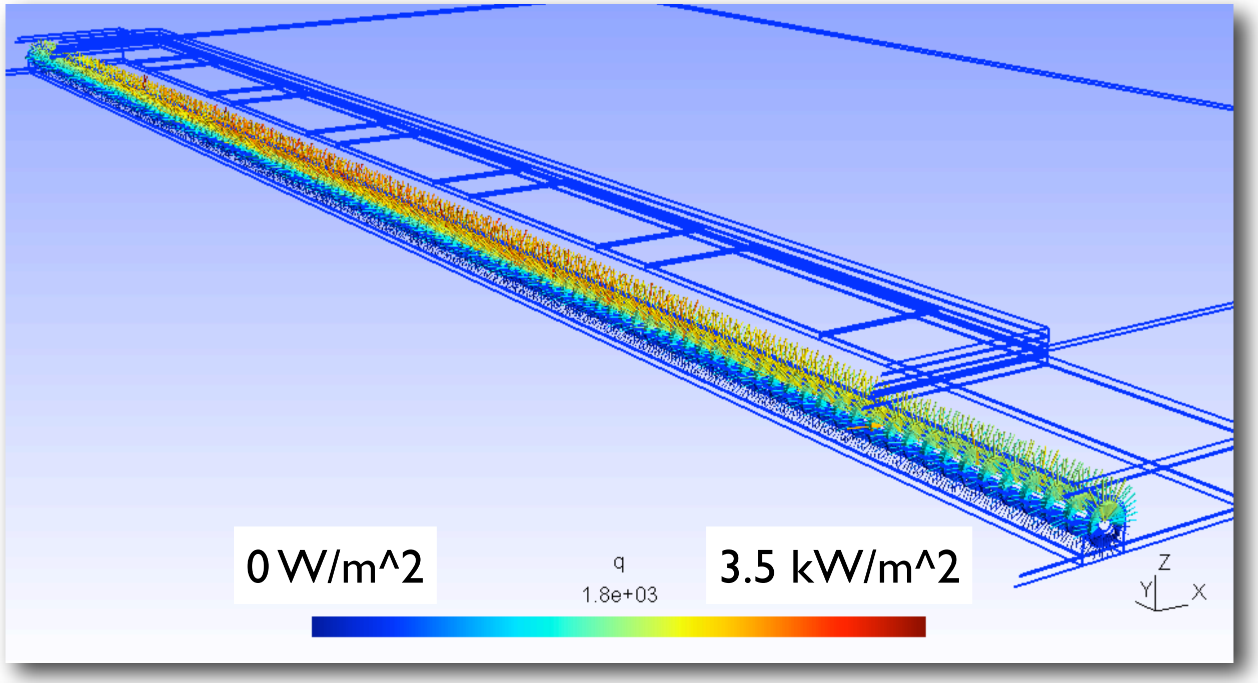
Long Cooling Contact Design with long Strixel



- Inner surface of **CO_2 layer** kept at reference temperature

Long Cooling Contact Design with long Strixel - Distributions





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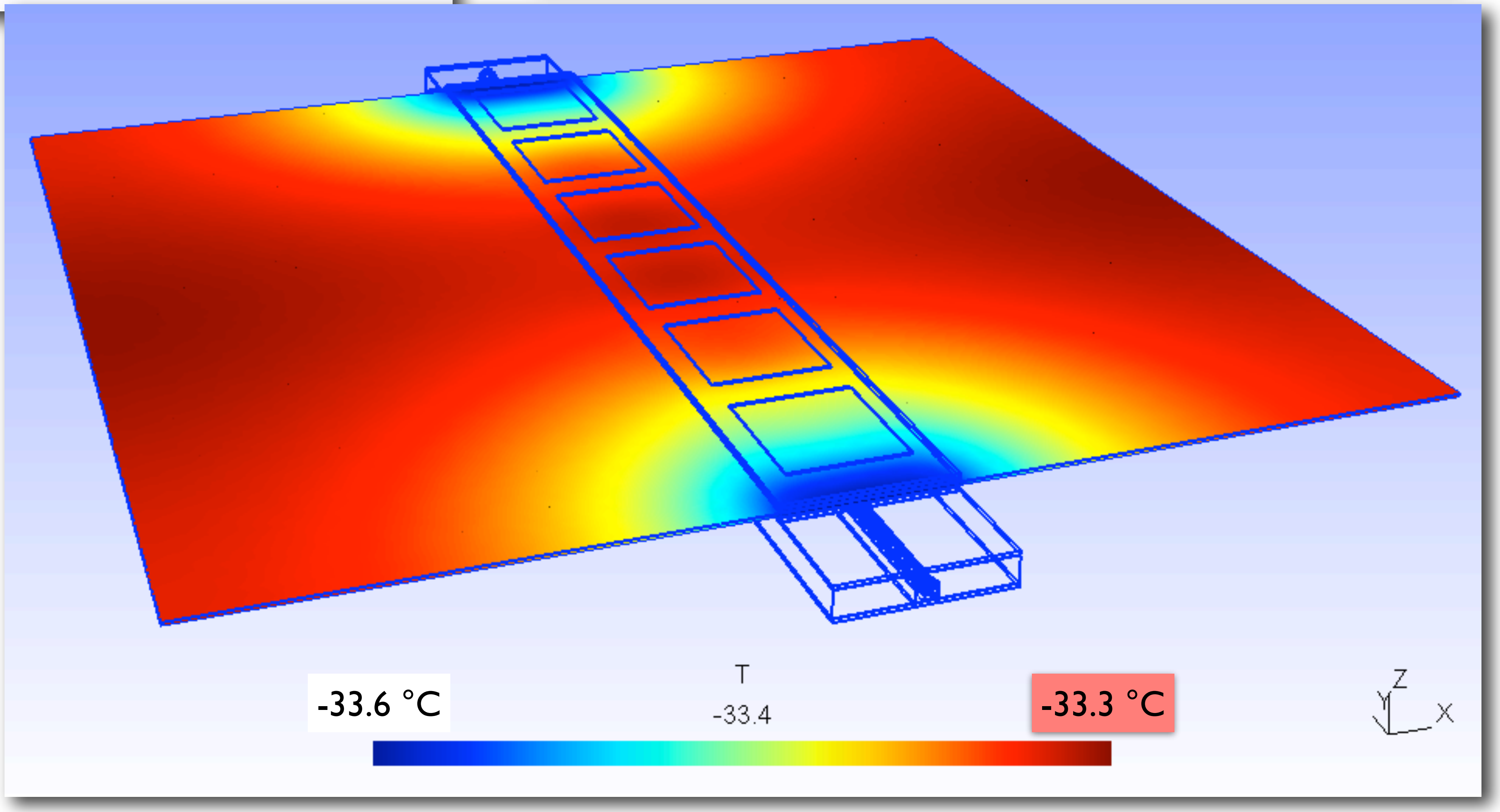
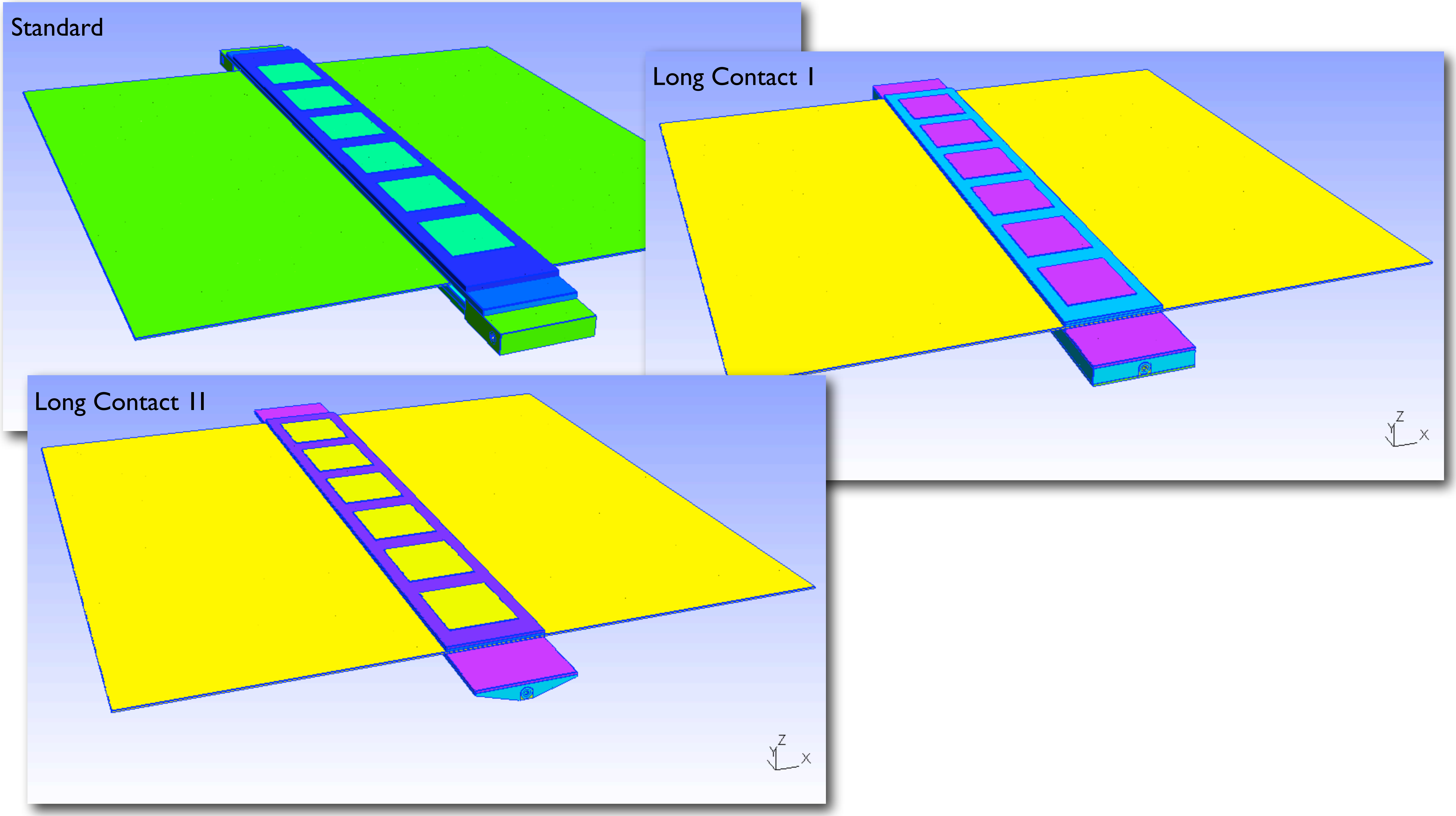
CO_2 temp: -35°C

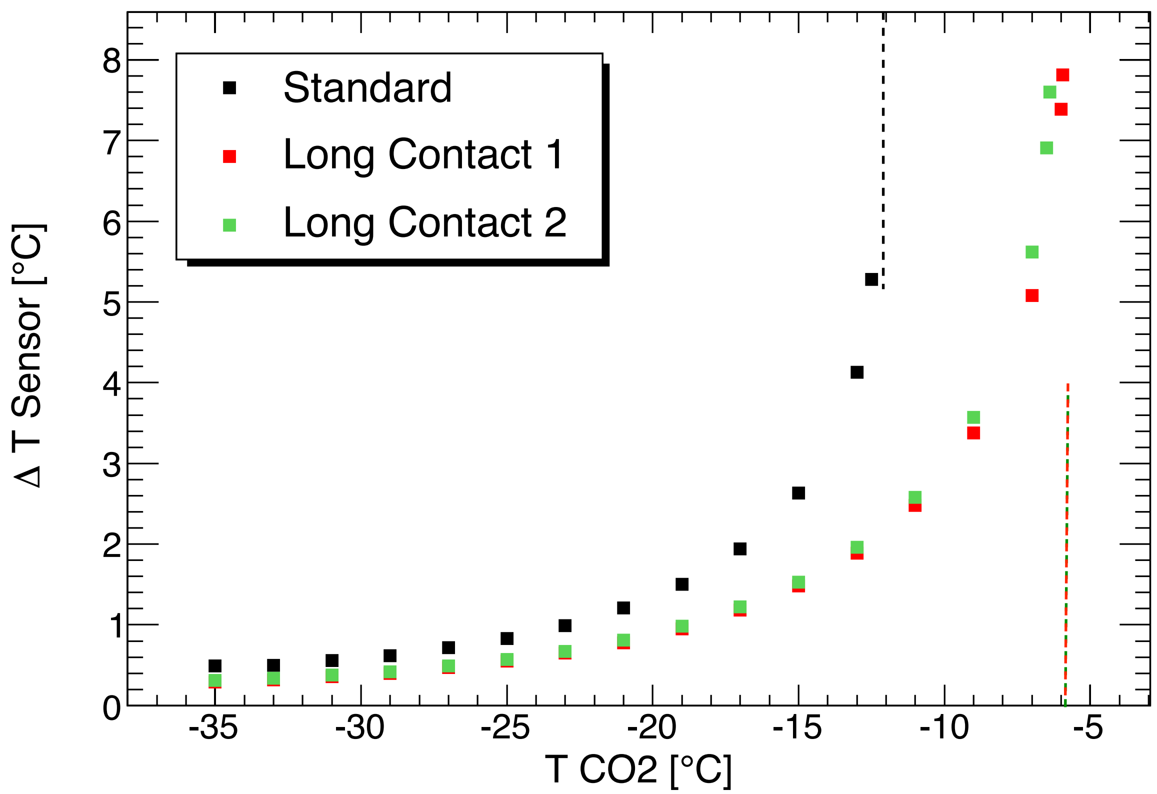


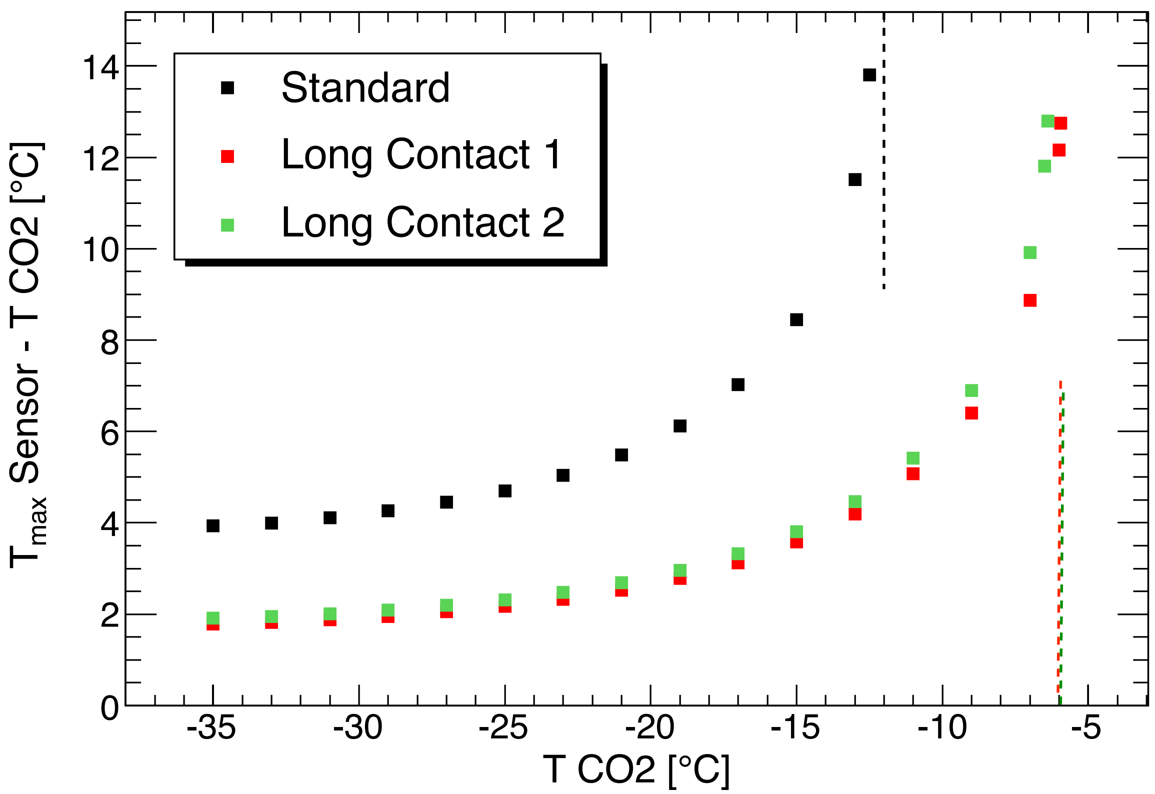
Long Strixel Comparison

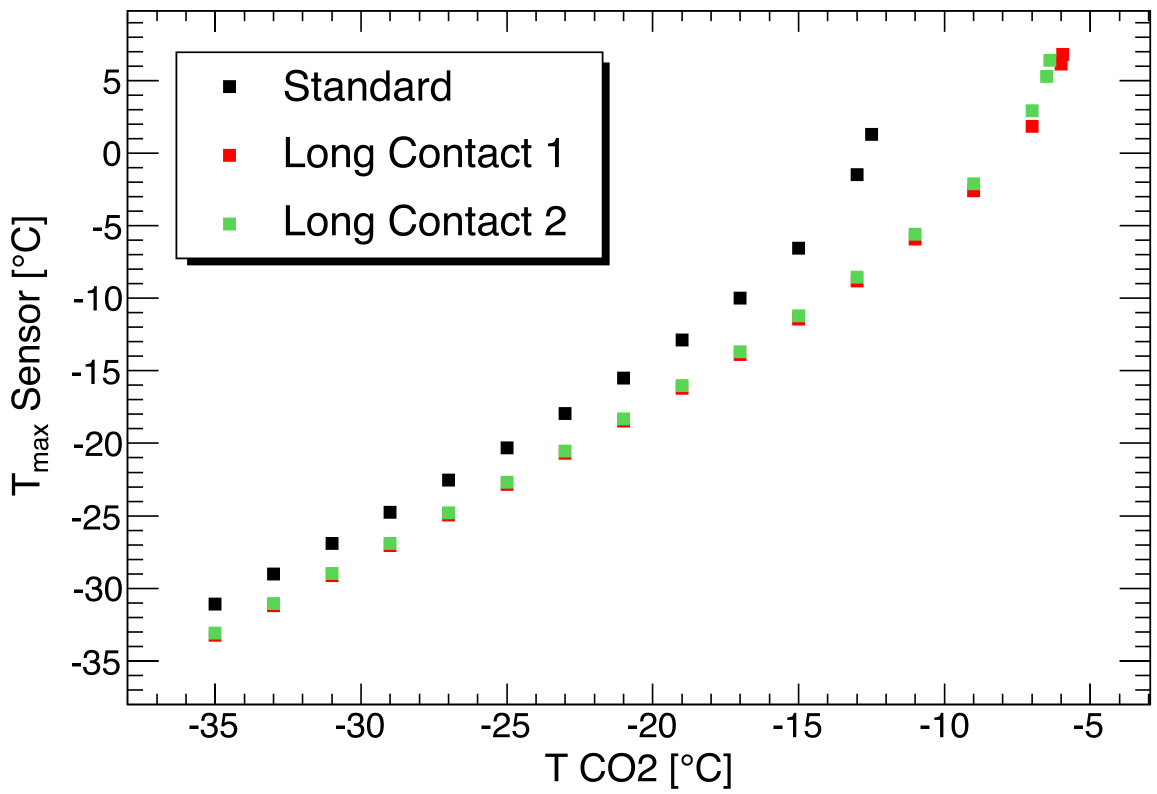


- Sensor power calculated for a fluence of 1.7e+14 @ 600V bias voltage
- CBC power: 0.750 W

Long Strixel Comparison - Thermal Runaway







Fluence: 1.7e14
CBC power: 0.750 W (125 mW per chip)

- Thermal runaway
  - Standard: ~ -12 °C
  - Long Contact: ~ -6 °C
- No difference between Long Contact options

Long Strixel Comparison - Material

Long Contact I

Sensor	2.000 cm^3	2.330 g/cm^3	4.660 g	
Hybrid	0.420 cm^3	2.000 g/cm^3	0.840 g	
CBC	0.072 cm^3	2.330 g/cm^3	0.168 g	
CFModule	0.924 cm^3	1.750 g/cm^3	1.617 g	2.3 g
Kapton	0.140 cm^3	1.850 g/cm^3	0.259 g	
GlueModule	0.316 cm^3	1.200 g/cm^3	0.379 g	
CFBase	3.856 cm^3	1.750 g/cm^3	6.748 g	8.1 g
GlueBase	0.188 cm^3	1.200 g/cm^3	0.226 g	
Pipe	0.147 cm^3	7.800 g/cm^3	1.147 g	
sum	8.063 cm^3	1.990 g/cm^3	16.044 g	

Long Contact II

Sensor	2.000 cm^3	2.330 g/cm^3	4.660 g	
Hybrid	0.420 cm^3	2.000 g/cm^3	0.840 g	
CBC	0.072 cm^3	2.330 g/cm^3	0.168 g	
CFModule	0.924 cm^3	1.750 g/cm^3	1.617 g	2.3 g
Kapton	0.140 cm^3	1.850 g/cm^3	0.259 g	
GlueModule	0.316 cm^3	1.200 g/cm^3	0.379 g	
CFBase	1.961 cm^3	1.750 g/cm^3	3.432 g	4.7 g
GlueBase	0.104 cm^3	1.200 g/cm^3	0.125 g	
Pipe	0.147 cm^3	7.800 g/cm^3	1.147 g	
sum	6.085 cm^3	2.075 g/cm^3	12.628 g	

Standard

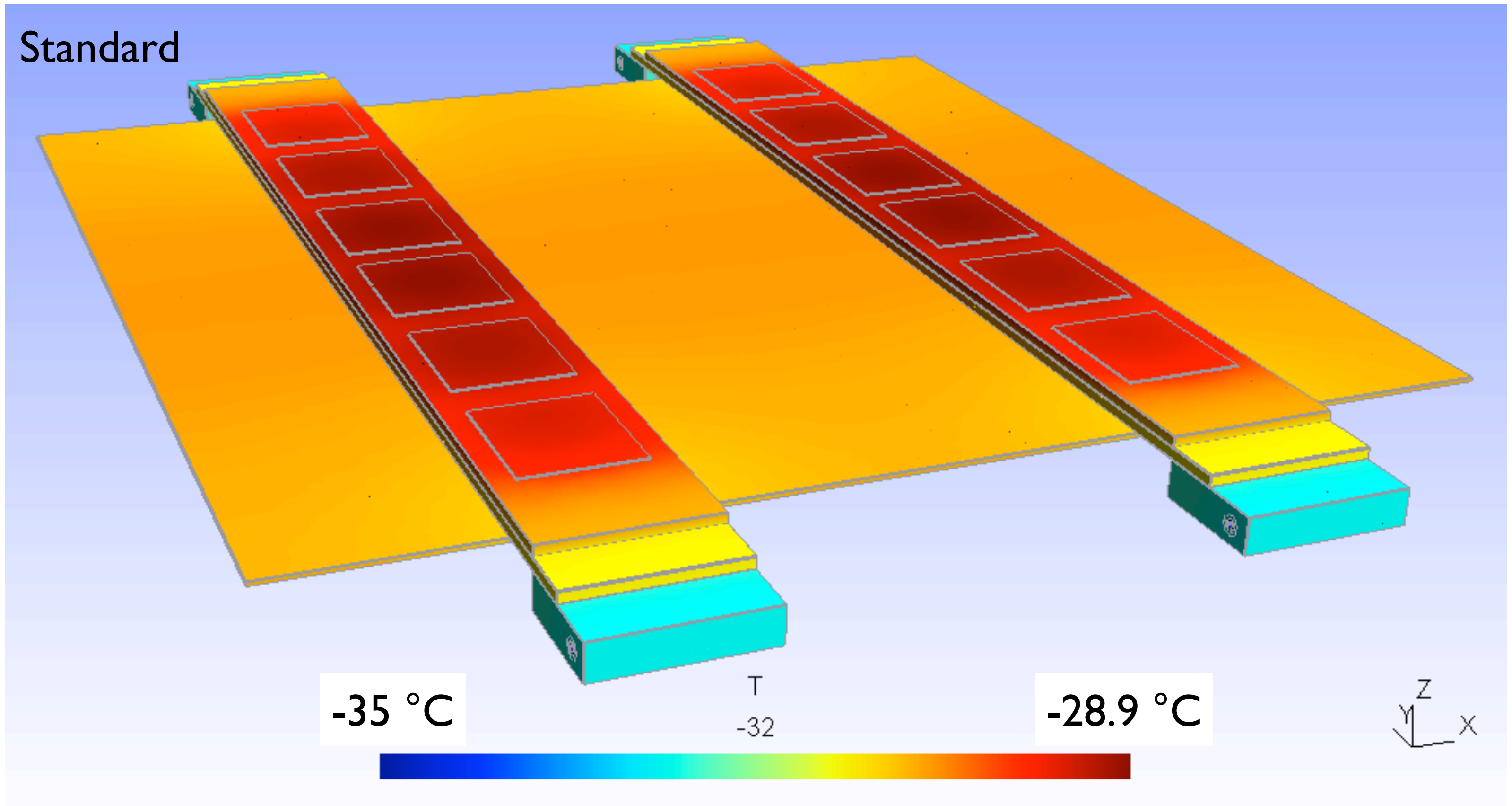
Sensor	2.000 cm^3	2.330 g/cm^3	4.660 g	
Hybrid	1.232 cm^3	2.000 g/cm^3	2.464 g	
CBC	0.072 cm^3	2.330 g/cm^3	0.168 g	
CF	0.336 cm^3	1.750 g/cm^3	0.588 g	3.9 g
TPG	1.344 cm^3	2.260 g/cm^3	3.037 g	
Glue	0.202 cm^3	1.200 g/cm^3	0.242 g	
CoolBlock	0.820 cm^3	2.700 g/cm^3	2.214 g	
sum	6.006 cm^3	2.227 g/cm^3	13.373 g	

Orange: Components on module

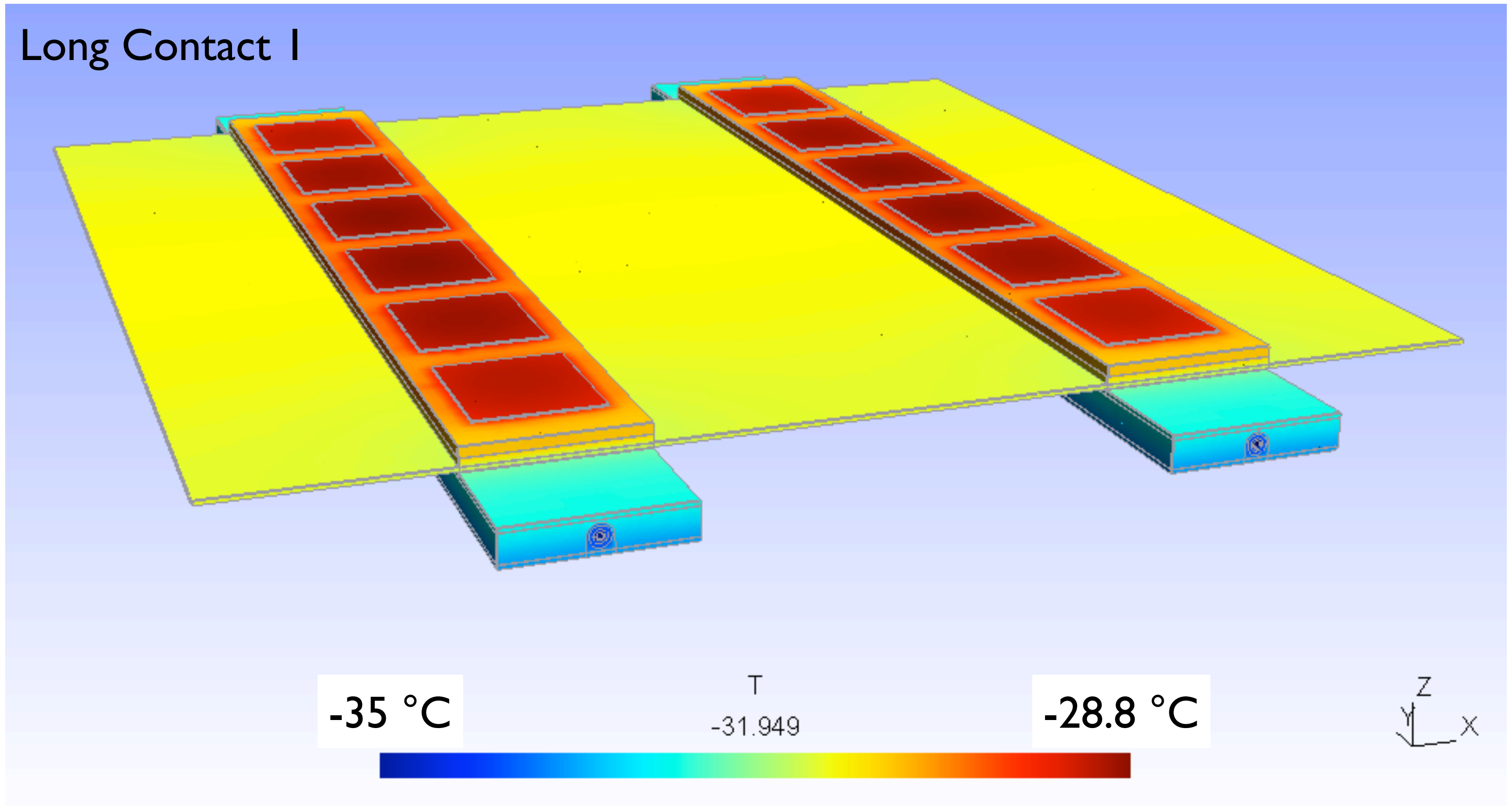
Olive: Components related to cooling and support

Design	(orange) + (olive)
Long Contact I	10.4 g
Long Contact II	7.0 g
Standard	6.1 g

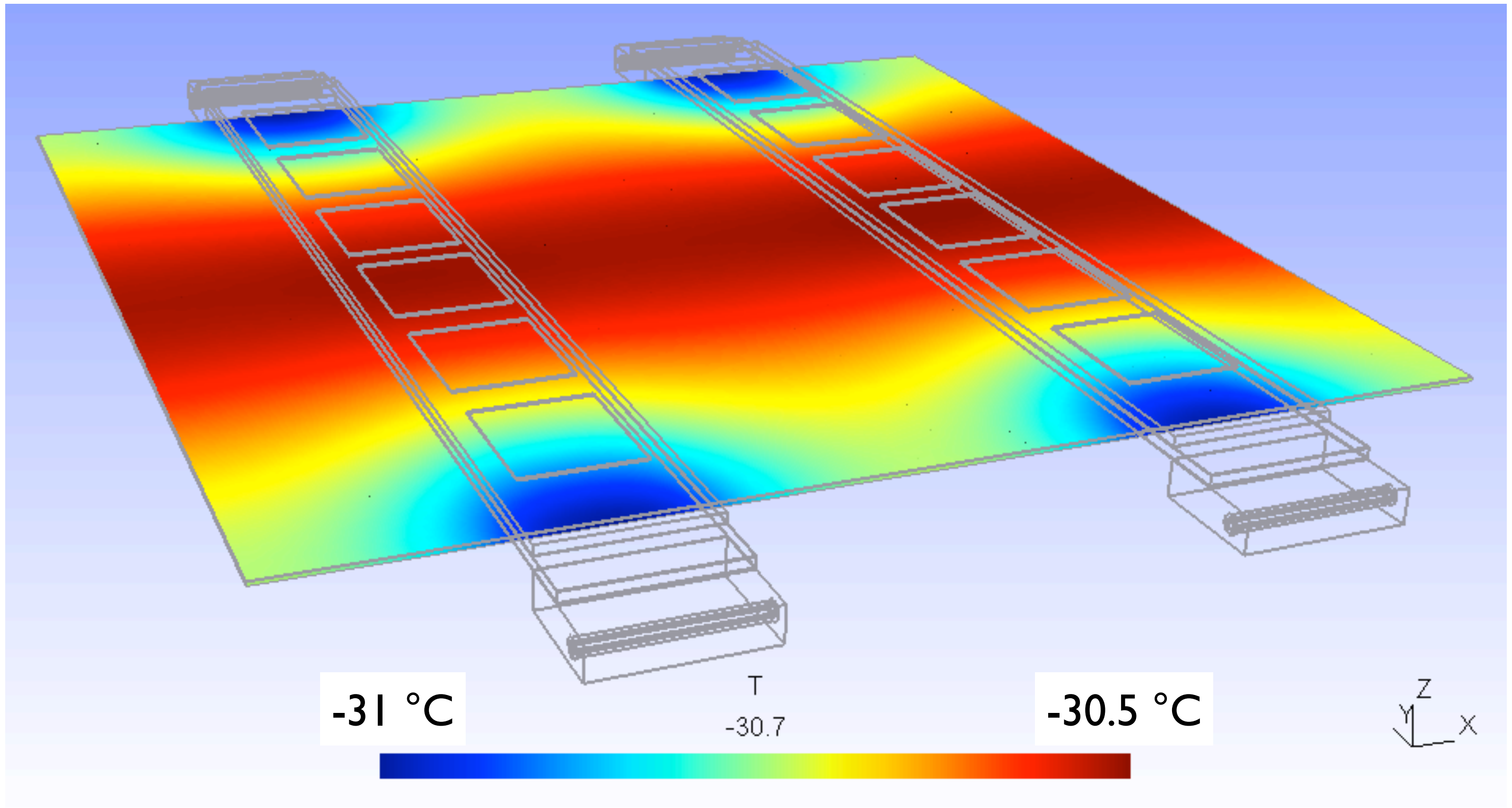
Short Strixel Comparison - Overall Temperature



Fluence: 4.3e14
CBC power: 1.50 W
CO_2 temp: -35°C



Short Strixel Comparison - Sensor Temperature



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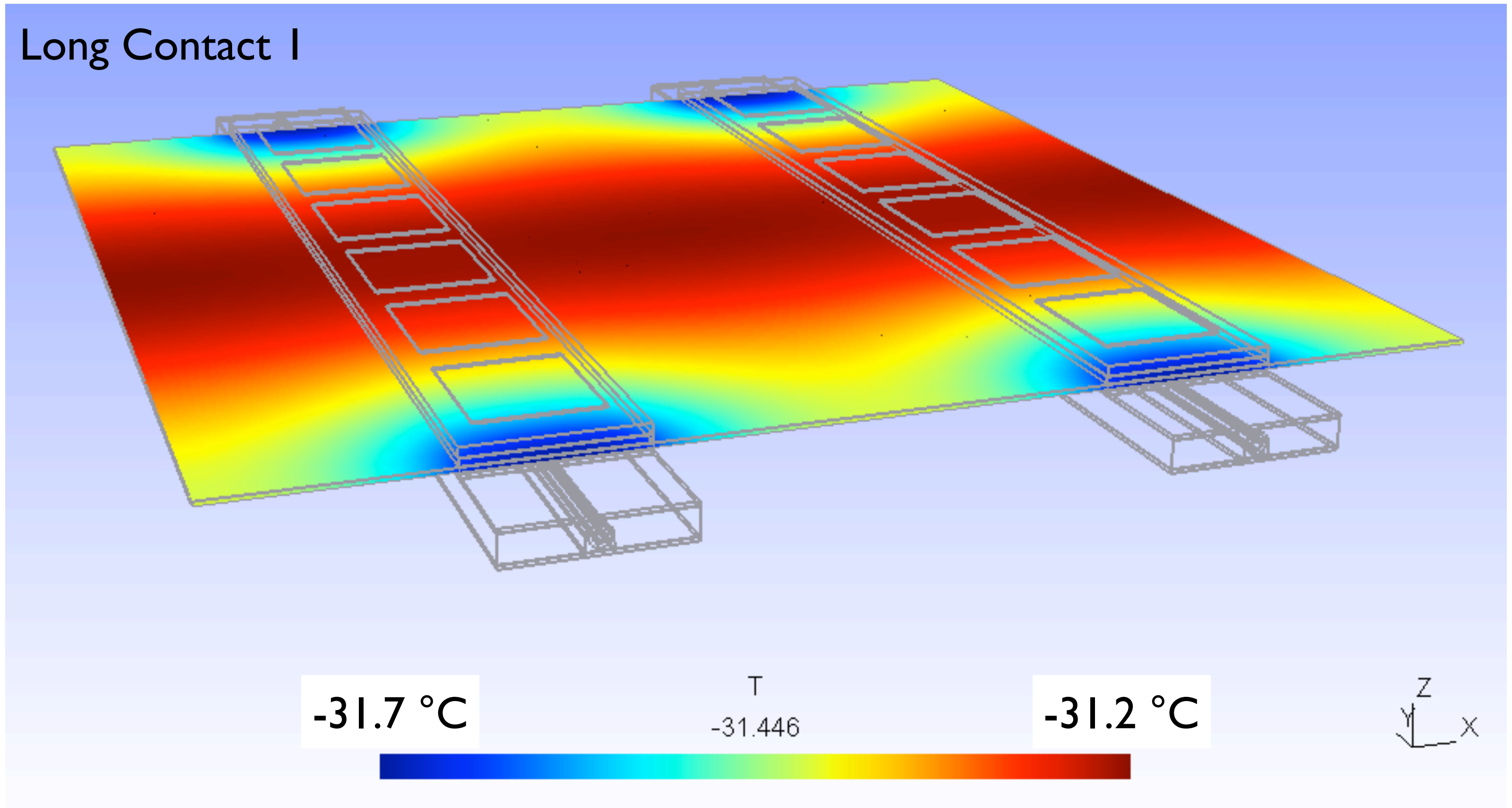
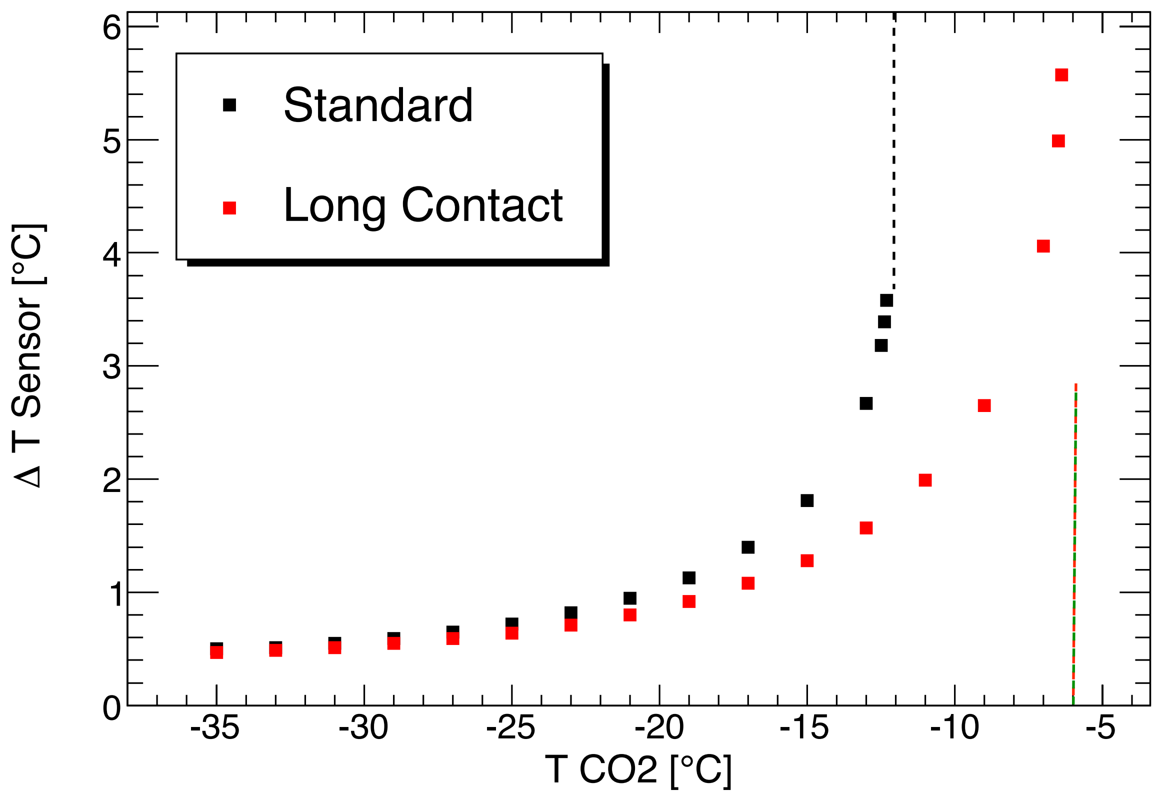
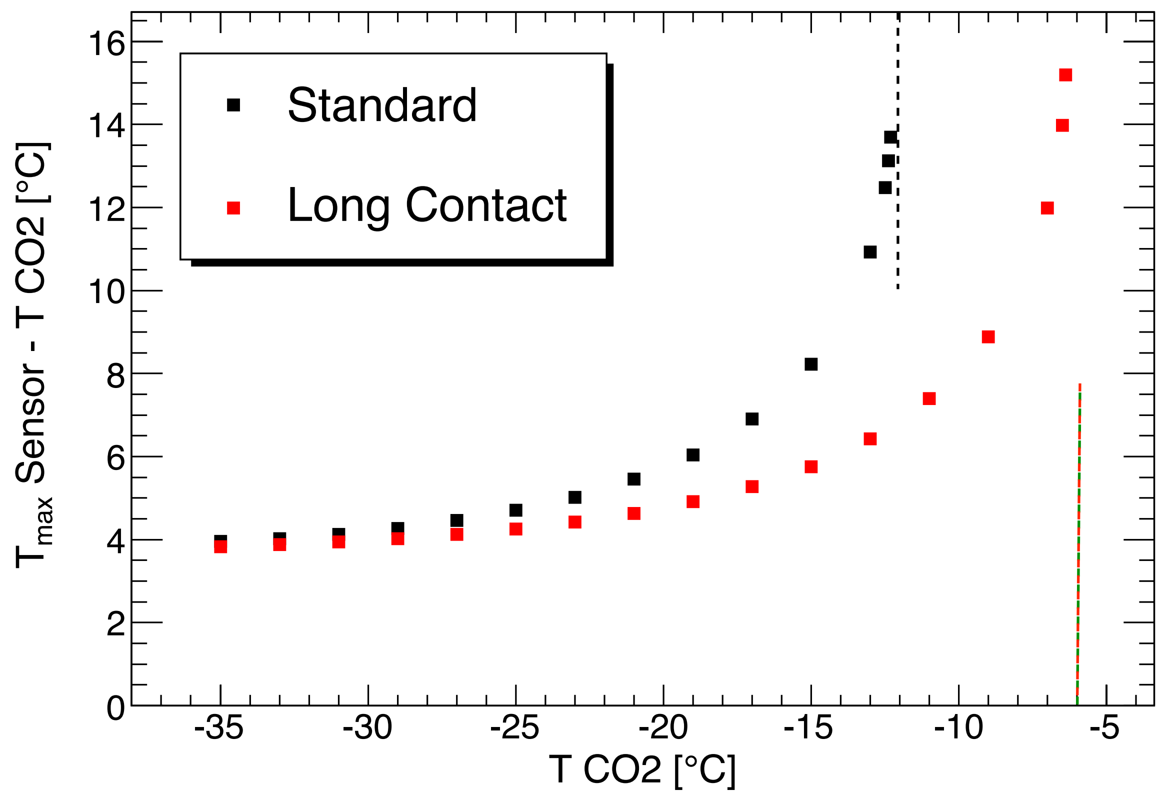
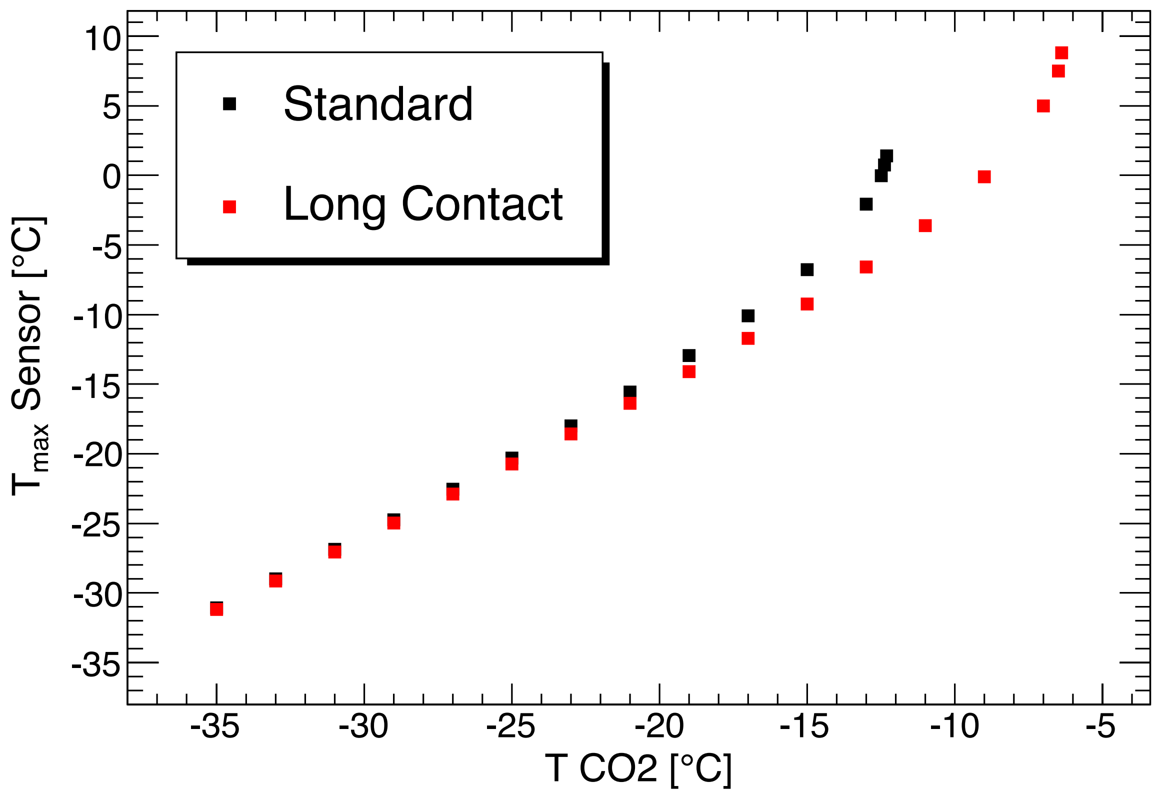


Short Strixel Comparison - Thermal Runaway







Fluence: 4.3e14
CBC power: 1.50 W (125 mW per chip)

- Thermal runaway
  - Standard: ~ -12 °C
  - Long Contact: ~ -6 °C

Summary

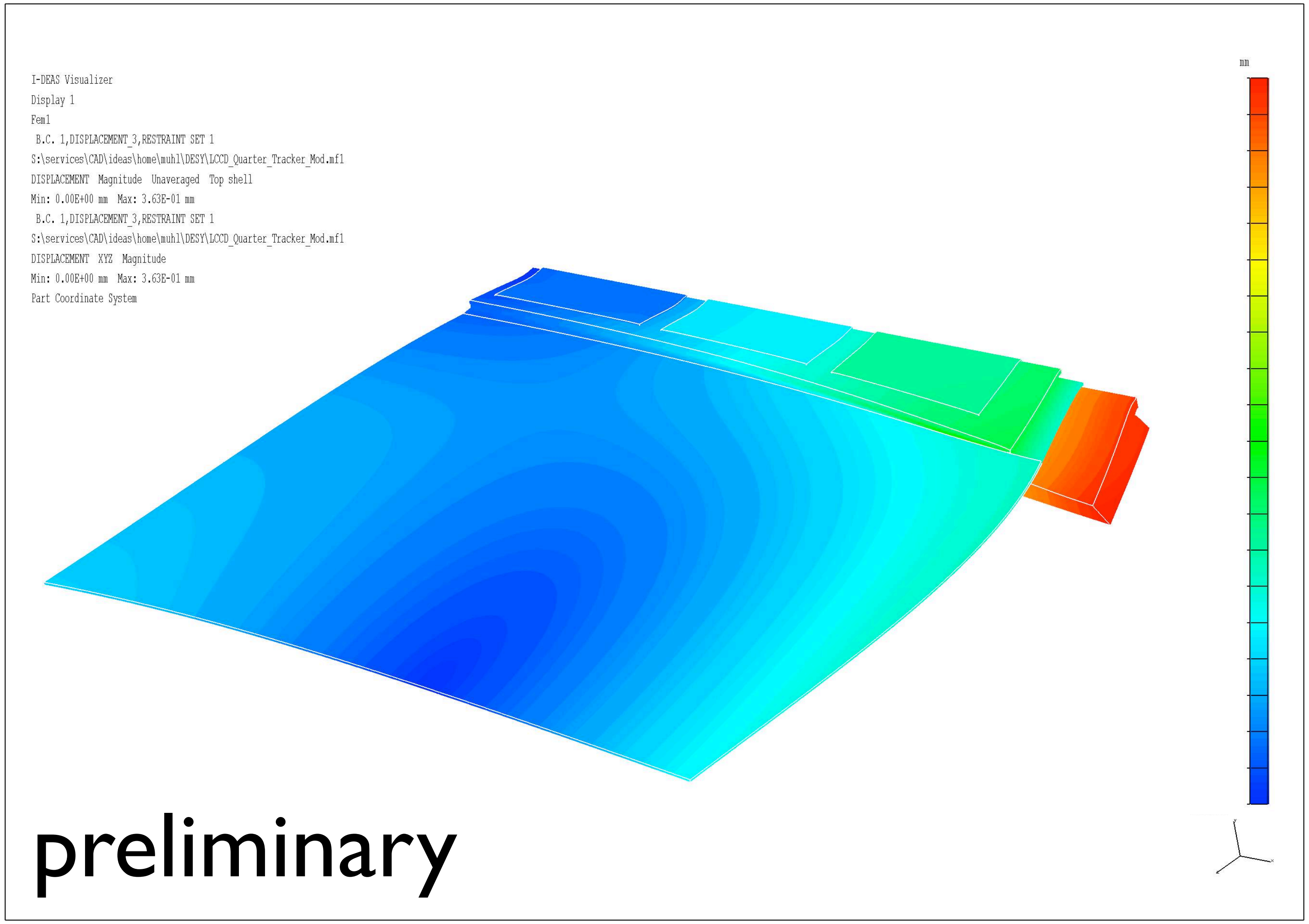
- DESY and UCSB FE calculations show very similar results
- Modelling heat transfer from CO_2 to pipe increases max. sensor temperature by ~2 °C for *Standard Design* (at -35 °C and fluence of 1.7e14)
- Standard Design

  Thermal runaway point at ~ -12 °C (both long and short strixel)
- Long Contact Design

  Thermal runaway point at ~ -6 °C (both long and short strixel)
- Material budgets of both designs are compareable (long and short strixel)

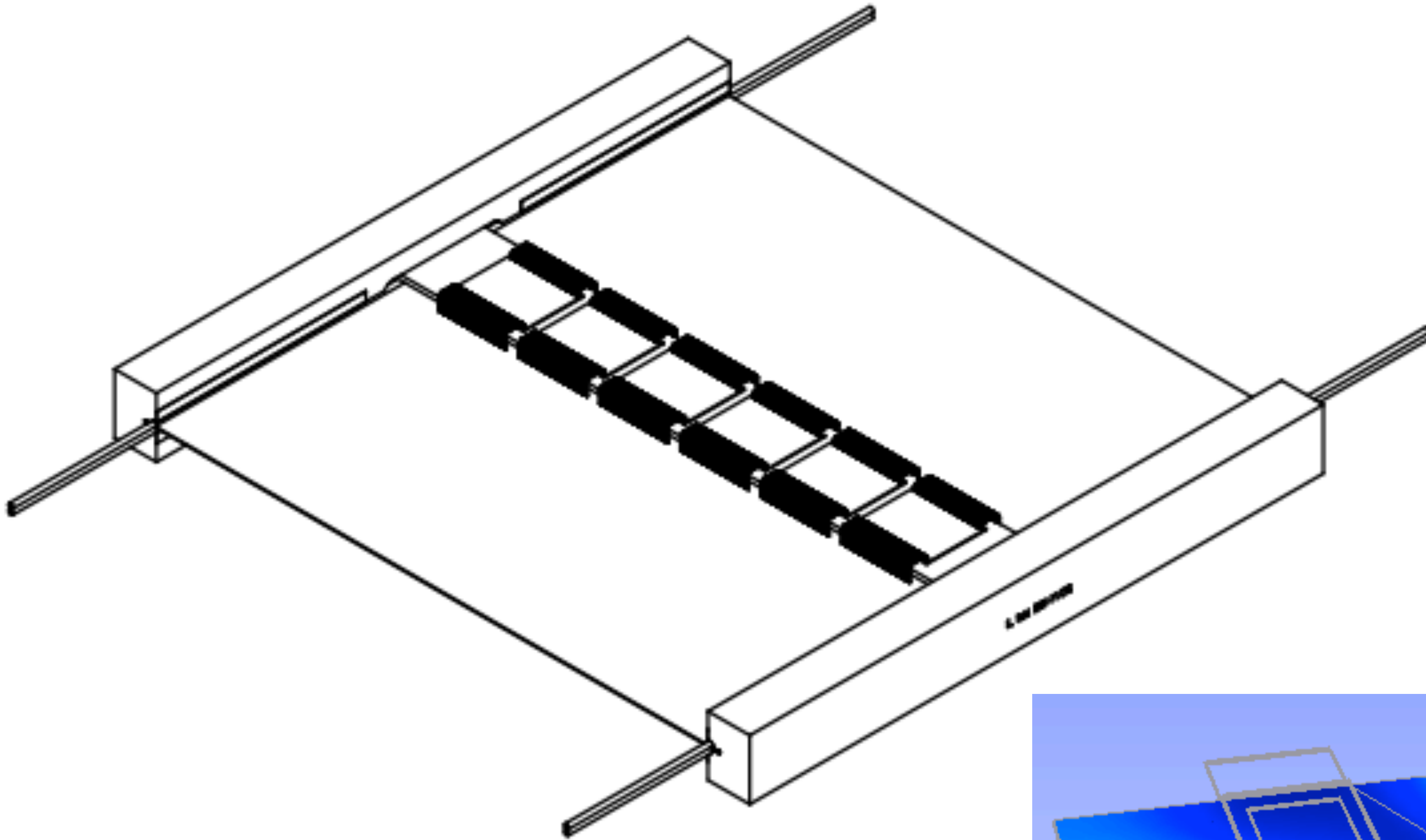
Outlook I

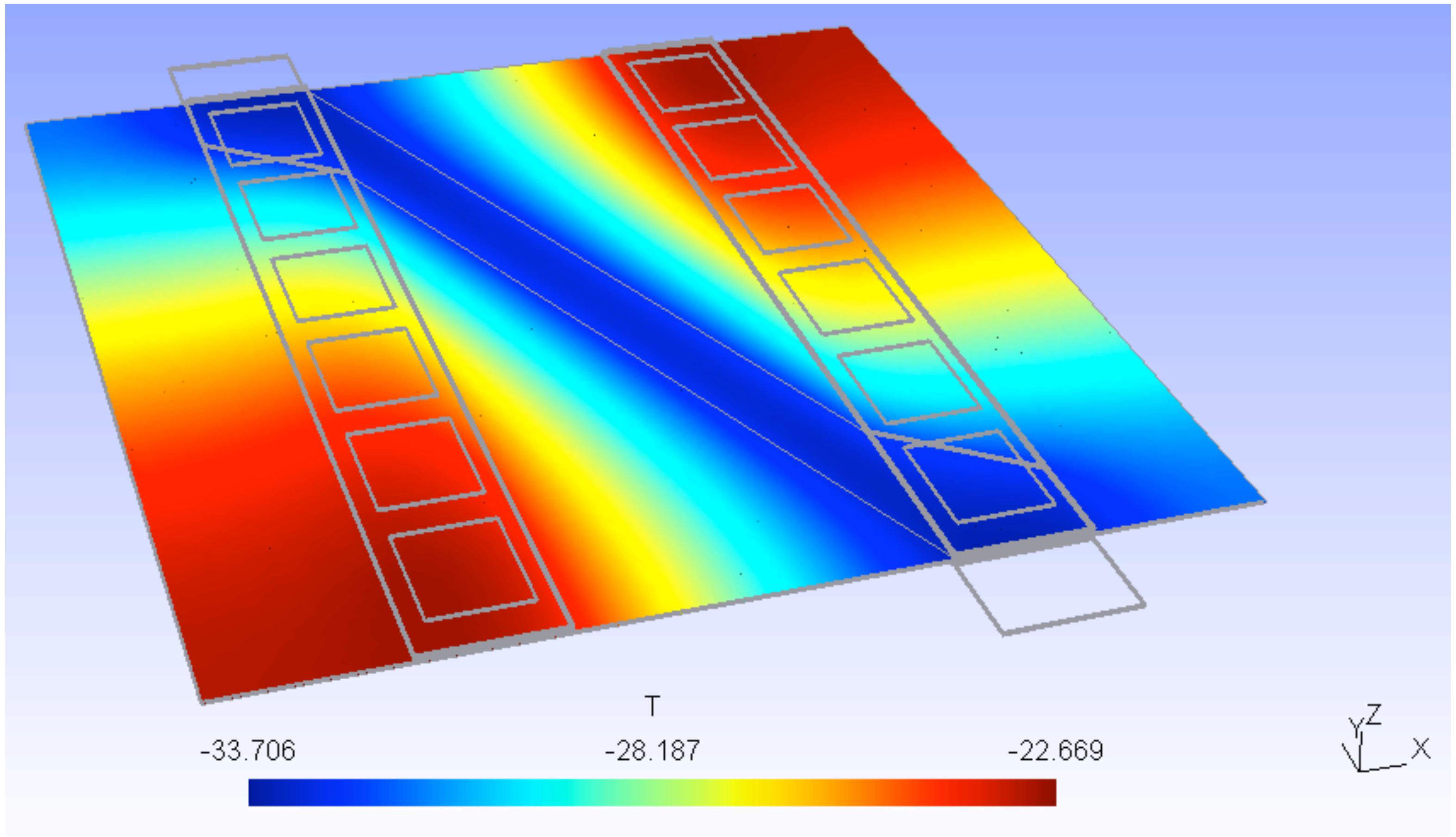
- Update calculations based on results from lab measurements (see talk by Jan)
- Continue with mechanical FE calculations
  - Not possible with getDP ➟ switch to I-DEAS
  - Mesh quality suffers from module proportions
  - Finer mesh means longer calculation time (10 days for first trial already exploiting symmetries)



Outlook II

- Continue looking for other design options





Backups

Materials for Standard Design Comparison

component	in-plane thermal conductivity [W/m*K]	out-of-plane thermal conductivity [W/m*K]
sensor and CBC	148	148
glue	1.5	1.5
CFK	63	0.4
TPG	1500	20
G10	0.3	0.3
Copper	391	391
Hybrid	0.76	0.76
Aluminum	240	240

- Thermal conductivity values match those used by UCSB