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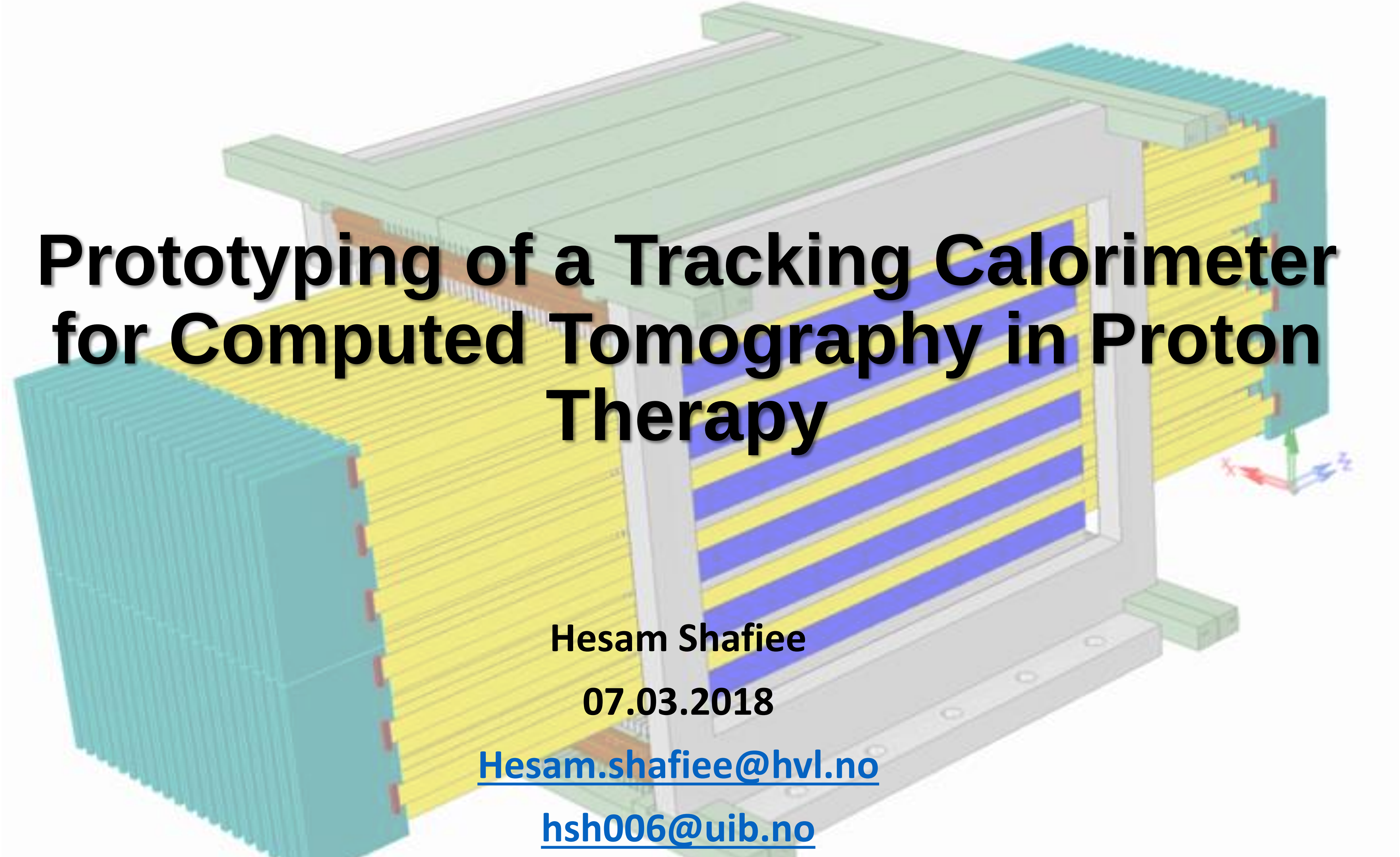

# Prototyping of a Tracking Calorimeter for Computed Tomography in Proton Therapy

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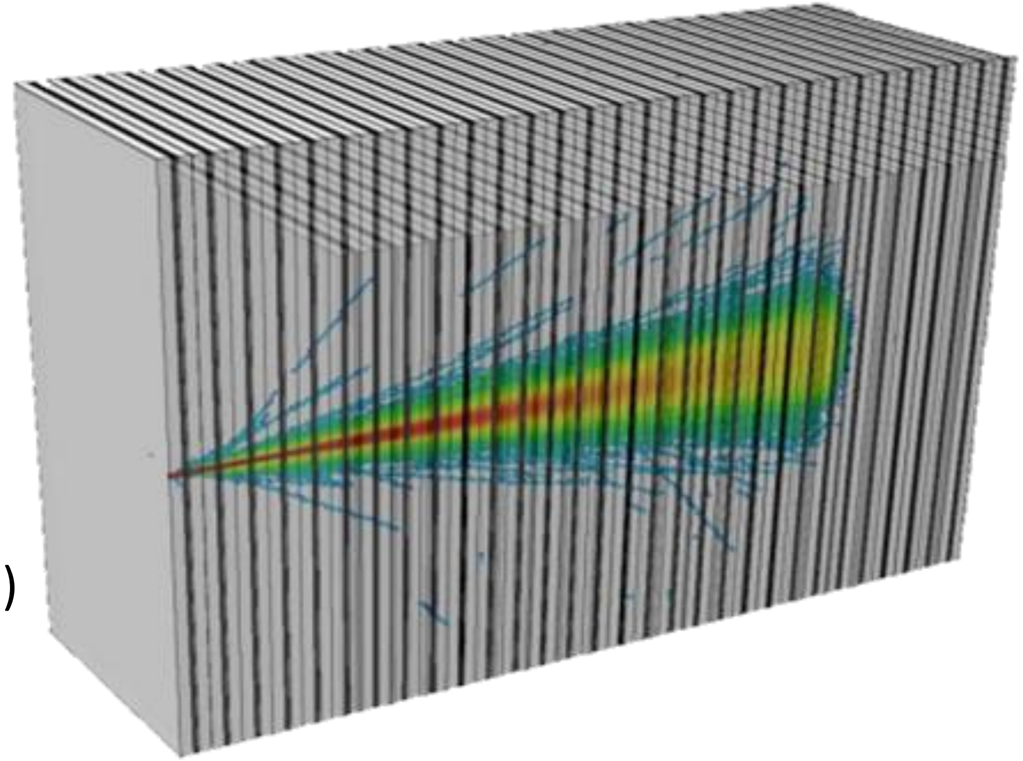
# WP5: Mechanical Package

- **Digital Tracking Calorimeter(Design parameters)**

Specification & sensitivity:

- ➡ Number of absorber layers for stopping protons
- ➡ Absorber thickness
- ➡ Material (Al, W, etc.)
- ➡ Material uniformity along proton trajectory
- ➡ Mechanical stability
- ➡ Fabrication & manufacturing aspect
- ➡ Clinical considerations
- ➡ Chip & readout electronics (mounting, sensitive area)
- ➡ Bonding method
- ➡ Heat transfer & Cooling
- ➡ Mechanical deformation



# Digital Tracking Calorimeter(DTC)

- **Number of absorber layers for stopping 230MeV protons**
- **Absorber thickness**

| Absorber thickness | Number of layers |
|---|---|
| 2 mm | ~63 |
| 3 mm | ~45 |
| 4 mm | ~35 |
| 5 mm | ~29 |
| 6 mm | ~25 |

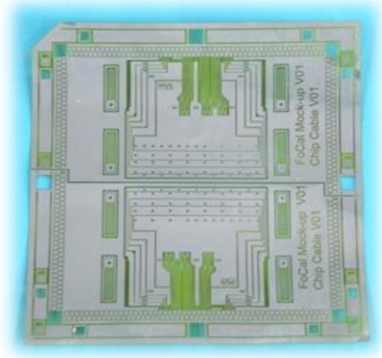
- **Material:**

  Mechanical properties such as density, stiffness

  Homogeneity

  Ionization energy

  Mechanica lintegrity, economy and clinical considerations



**(Slava)**

- **Material uniformity along proton trajectory**

  Electrical connectors, wirings

  Coolant channel

  Support structure

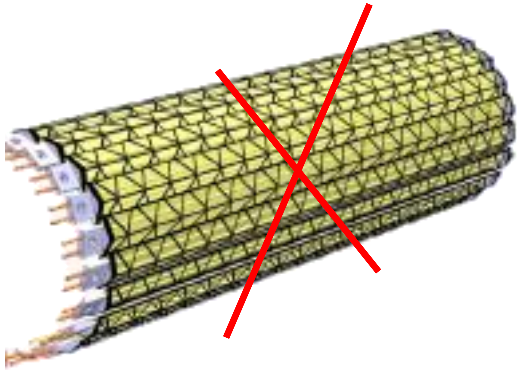


**Figure from ALICE ITS**

# Digital Tracking Calorimeter(DTC)

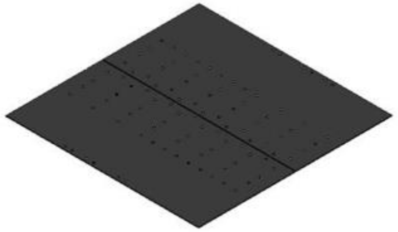
- **Mechanical Stability**
  Solid & stiff structure
  Assembly and maintenance reliability
  No vibration
  Production feasibility

- **Fabrication & manufacturing aspects**
  machining, filing, cutting, welding, casting!?

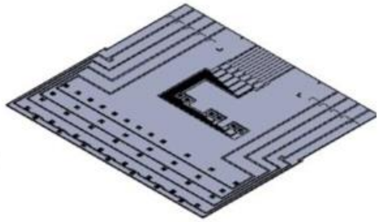
- **Clinical considerations**
  Working temperature range
  No poisonous material
  Coolant leakage
  Short circuit

# Digital Tracking Calorimeter(DTC)

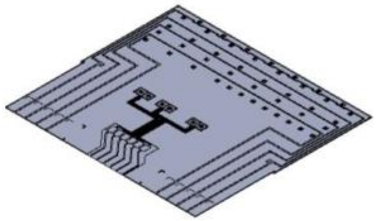
- **Chip & read-out electronics**
  - Chip size = 1.5cm x 3cm
  - Sensitive area = 18cm x 27cm
  - Space for data readout strip
  - Cooling methods & coolant channel
  - Uniformity



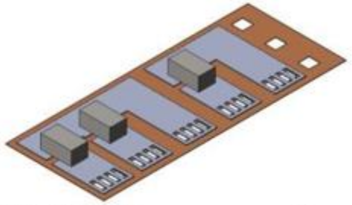
Alpide chip



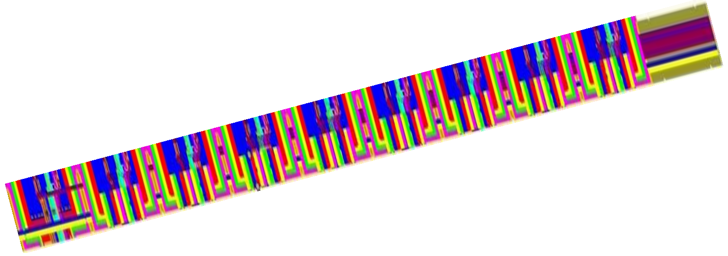
Chip Cable Type 1

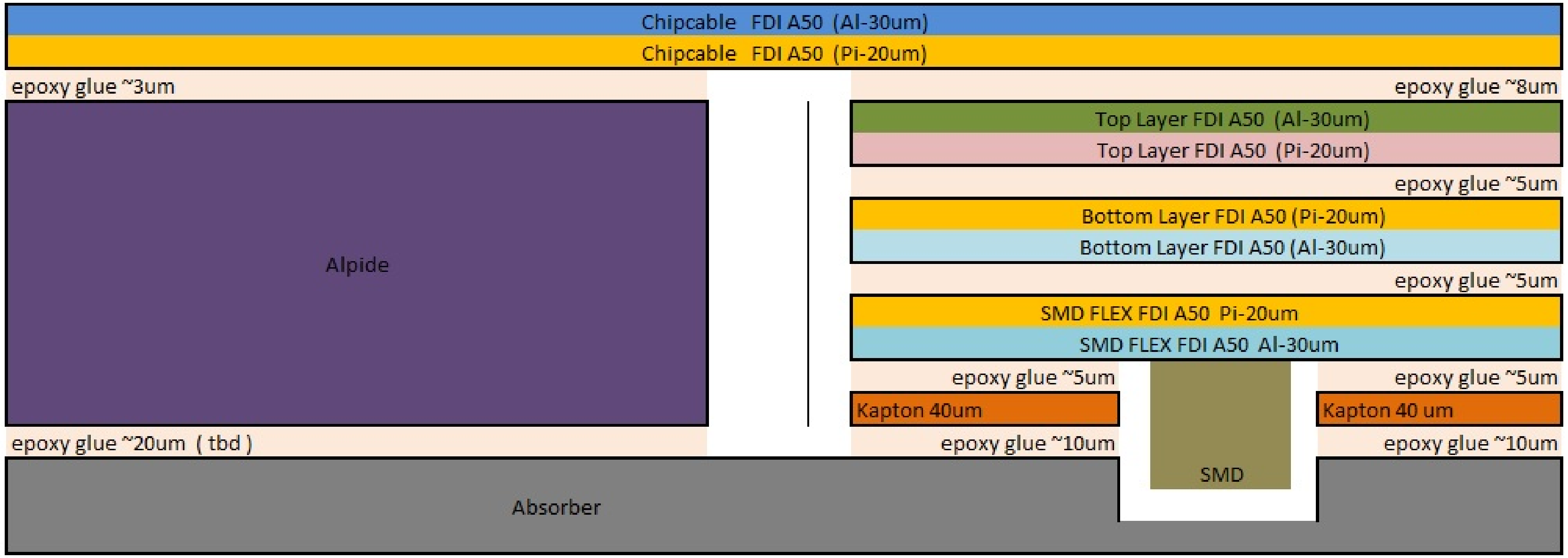


Chip Cable Type 2



SMD Flexmount





Chipcable FDI A50 (Al-30um)

Chipcable FDI A50 (Pi-20um)

epoxy glue ~3um

epoxy glue ~8um

Top Layer FDI A50 (Al-30um)

Top Layer FDI A50 (Pi-20um)

epoxy glue ~5um

Alpide

Bottom Layer FDI A50 (Pi-20um)

Bottom Layer FDI A50 (Al-30um)

epoxy glue ~5um

SMD FLEX FDI A50 Pi-20um

SMD FLEX FDI A50 Al-30um

epoxy glue ~5um

epoxy glue ~5um

Kapton 40um

Kapton 40 um

epoxy glue ~20um ( tbd )

epoxy glue ~10um

epoxy glue ~10um

SMD

Absorber

**Figures from Slava: ''9 Alpide string'' & Nikhef '' Mock up of Focal slab''**

# Digital Tracking Calorimeter(DTC)

- **Bonding method**

Mechanical Connection → Ultrasound welding

Dielectric connection Glue protection

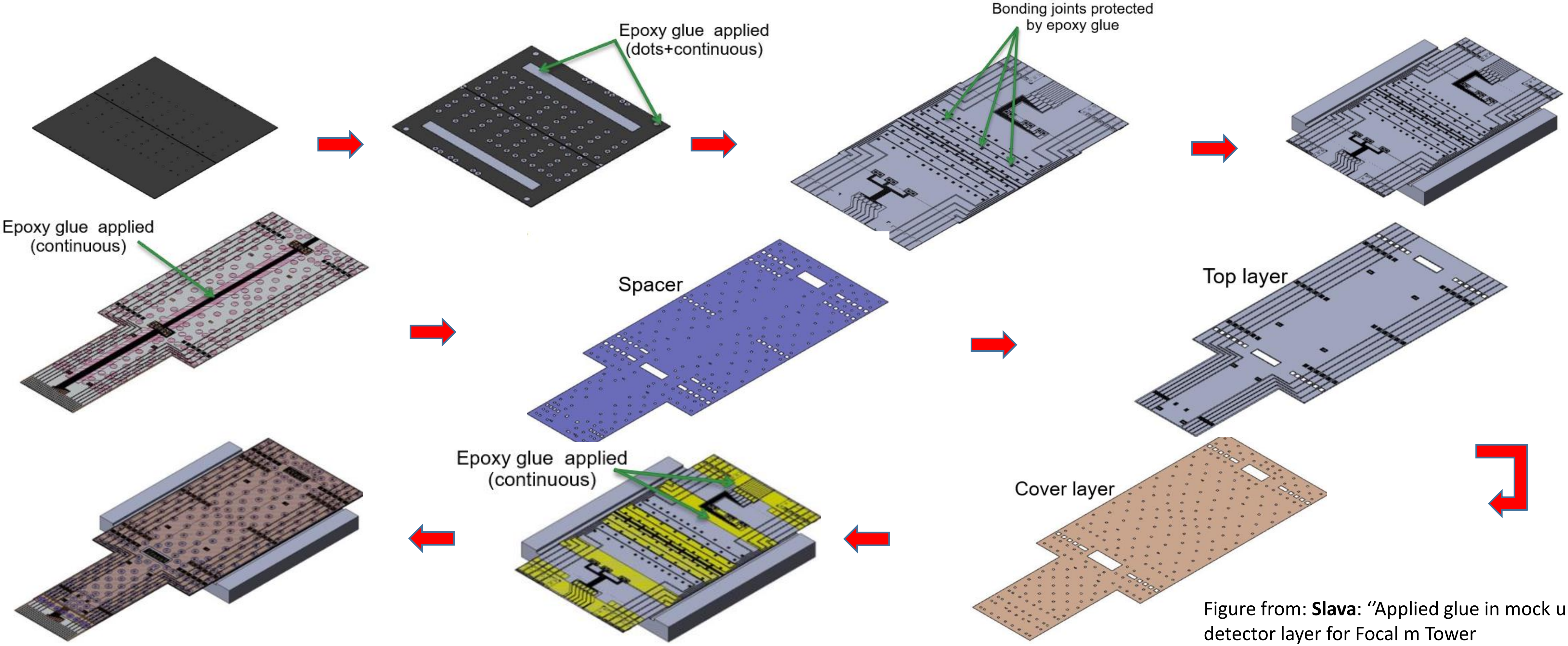


Figure from: **Slava**: ‘’Applied glue in mock up of detector layer for Focal m Tower

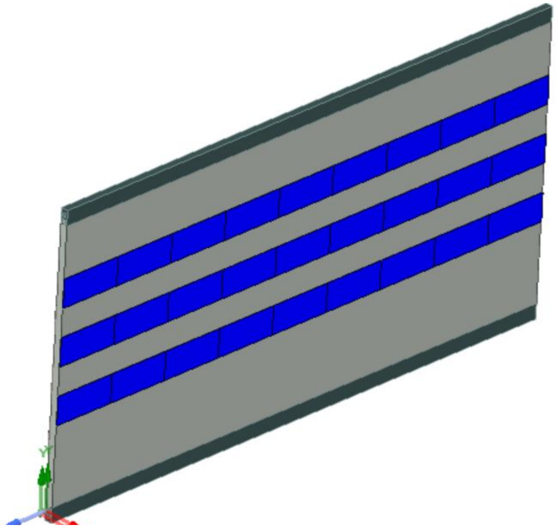
# Digital Tracking Calorimeter(DTC)

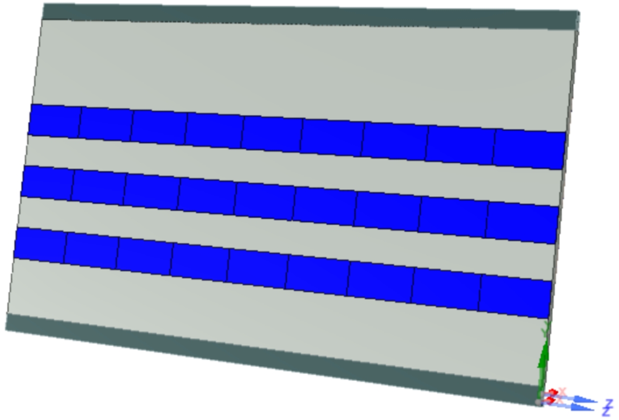
- **Sensitive area (placement of chips)**

→ 12 Rows, each with 9 chips side-by-side

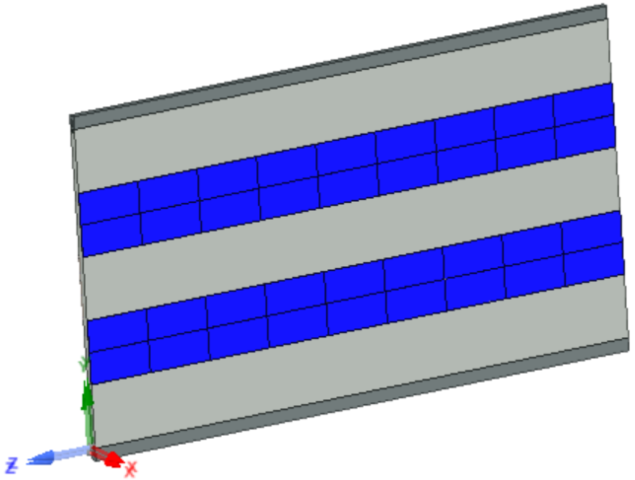
Two Scenarios:

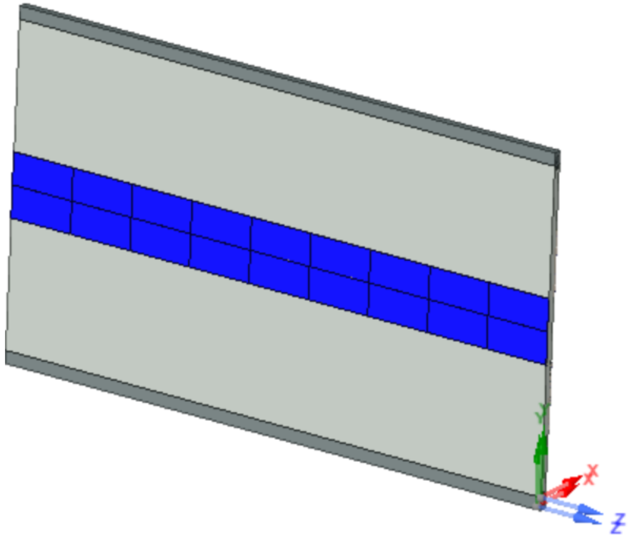
1)





2)

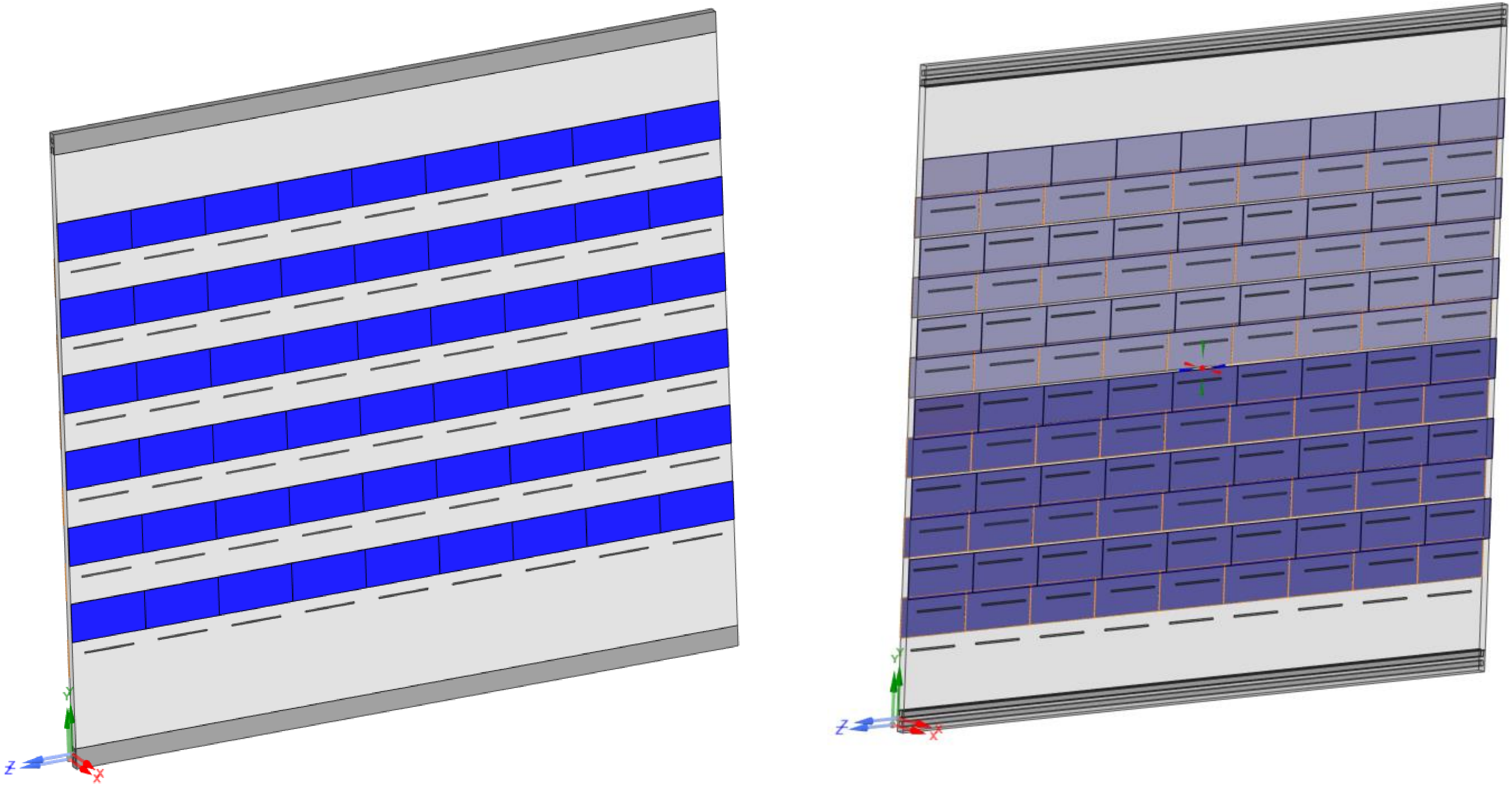




# Digital Tracking Calorimeter(DTC)

**Sensitive area (placement of chips):**

First scenario has been accepted due to better Temperature distribution

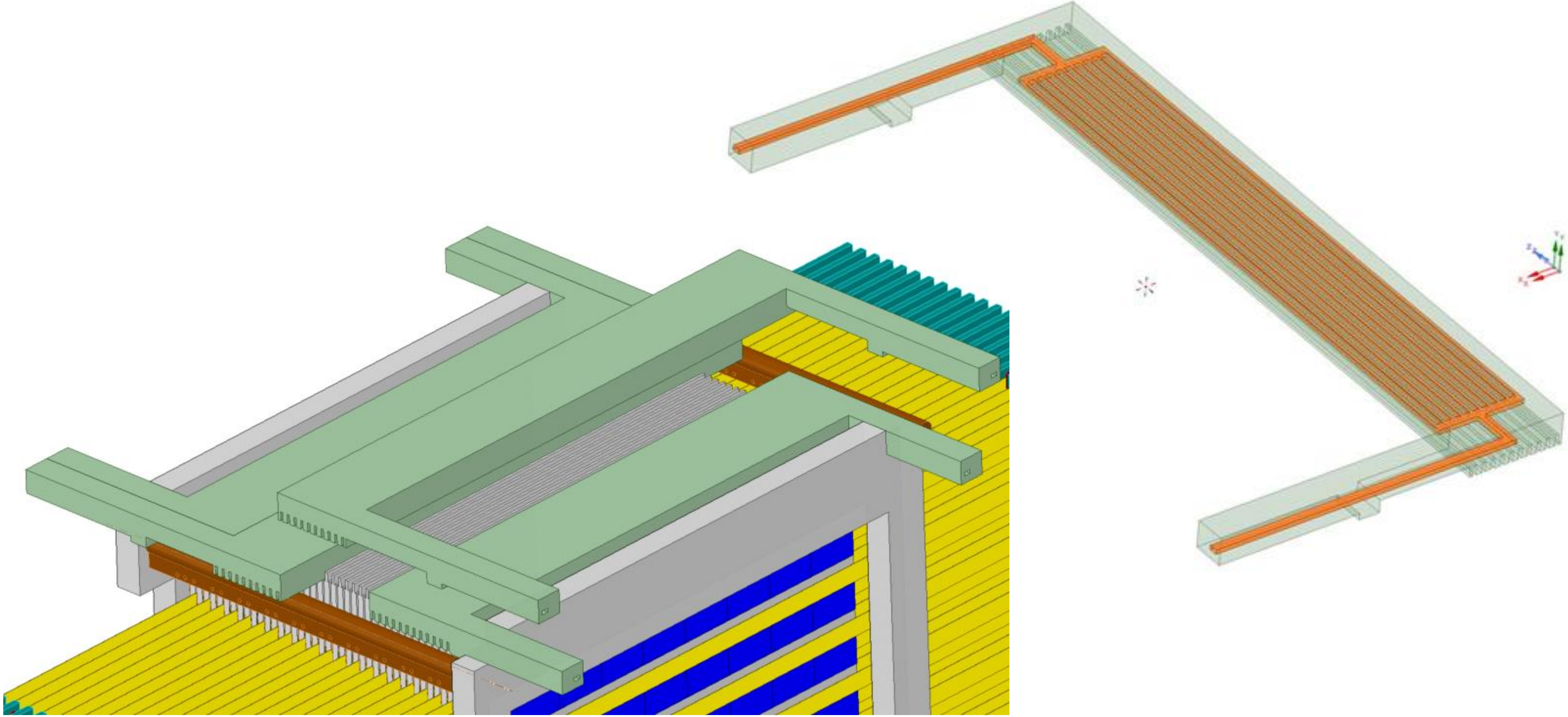


# Digital Tracking Calorimeter(DTC)

**Cooling mechanism**

Hollow top & bottom structure for coolant flow path

This structure grips 10 staves. By removing this, staves could be remove in packs of 4 by using hangrip & fork spacer element.



# Digital Tracking Calorimeter(DTC)

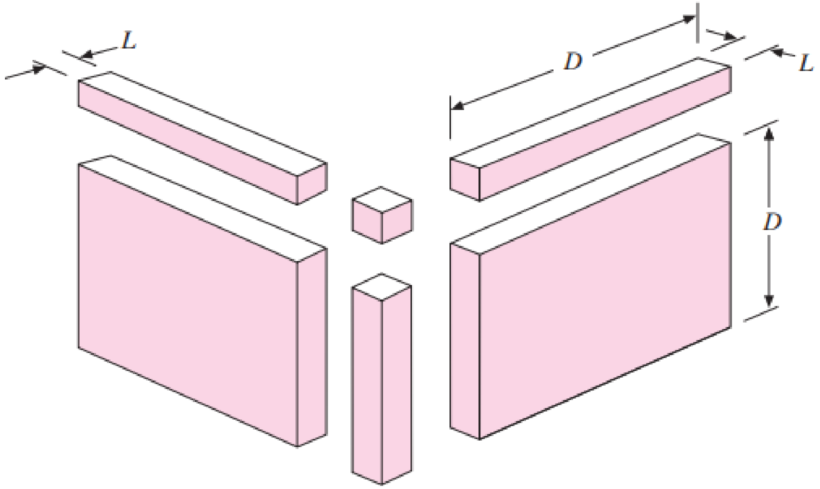
- **Heat Transfer & cooling**

➡ Heat distribution in single layer

Geometry effect (length-width proportion)

$q = k\ S\ \Delta T_{\text{overall}}$

S = Shape factor



- 2D Geometries

  Summary of shape factors for a large variety of geometries is given

- 3D geometries

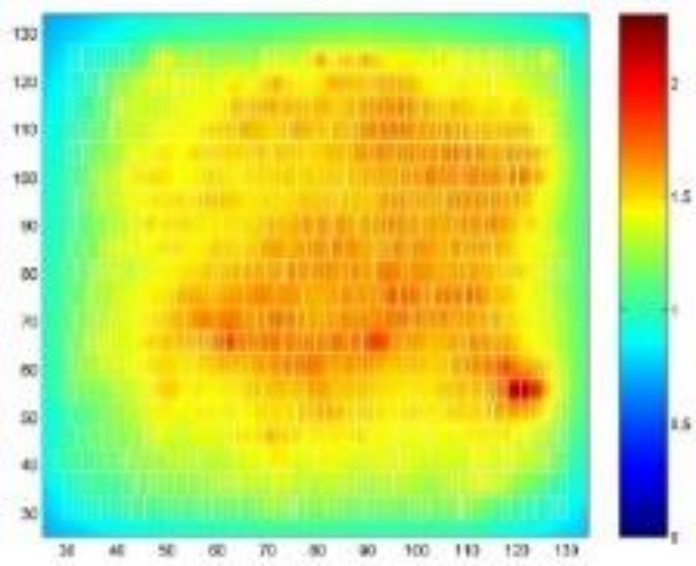
$S_{wall}$ = A /L $S_{\text{edge}}$ = 0.54D $S_{\text{corner}}$ = 0.15L

A = Area of wall

L = Wall thickness

D = Length of edge

# Digital Tracking Calorimeter(DTC)



- **Temperature gradient & heat transfer rate**

  High energy proton beams collision location/ electronic heat generation spots

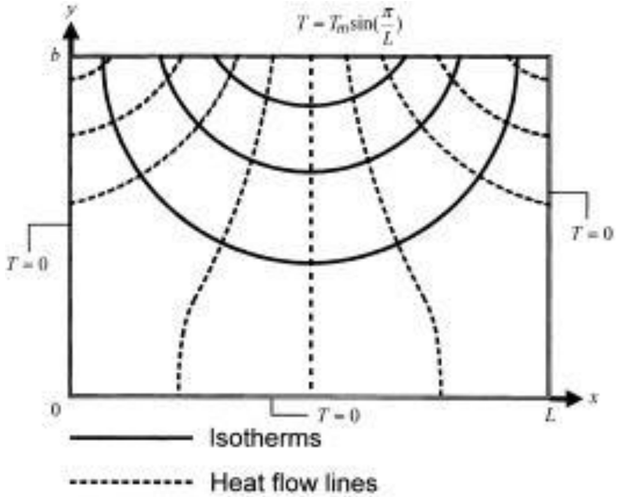
  ↪ energy gradient causes

  ↪ non-uniform temperature distribution

- **Increasing conductivity of plate**

  Material/Mechanical properties of chip, chip cables, bondings & absorber:

  Higher conductivity (k) ⟷ Higher rate of heat transfer



- **Heat spots and critical areas**
- **Effects of boundary conditions as cold sources**

# Digital Tracking Calorimeter(DTC)

- **Heat transfer through layers**

  - Thermal resistance of multilayer bodies($R_{Total}$):

    Sensors, PCB, Silver glue, absorber

    $$R=R1+R2+R3+R4+R5 = \frac{L_1}{k_1A_1} + \frac{L_2}{k_2A_2} + \frac{L_3}{k_3A_3} + \frac{L_4}{k_4A_4} + \frac{L_5}{k_5A_5}$$

    ↑ k , A ⟷ R ↓

  - Temperature gradient & rate of heat transfer

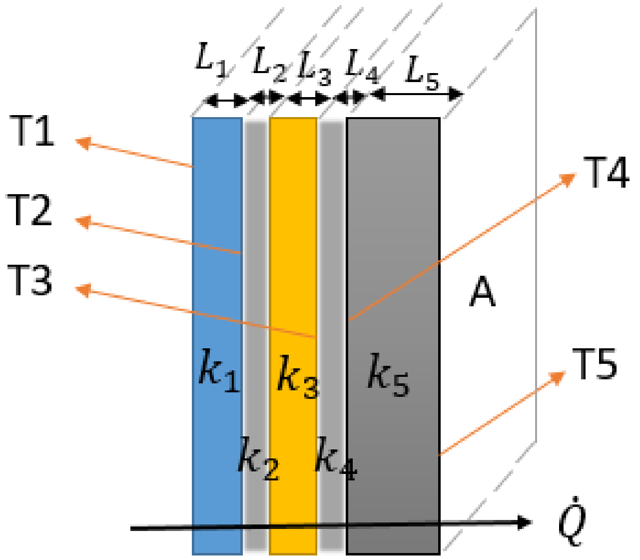
    $$\dot{Q} = \frac{\Delta T}{R}$$

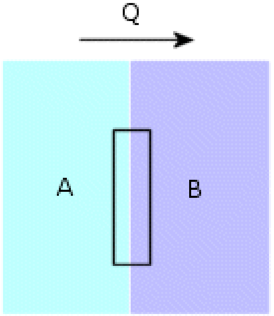
    ↑ ΔT ⟷ ↑ $\dot{Q}$

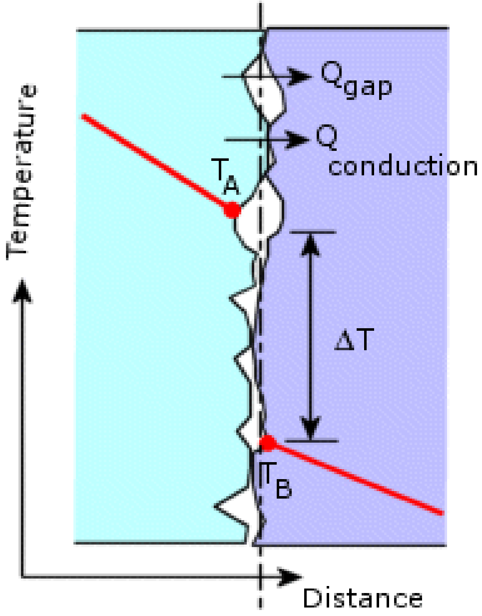
  - Thickness layers sensitivity ↑ L ⟷ $\dot{Q}$ ↓

  - Critical layer in case of mechanical properties and heat capacity, deformation?!

  - Thermal contact resistance challenge



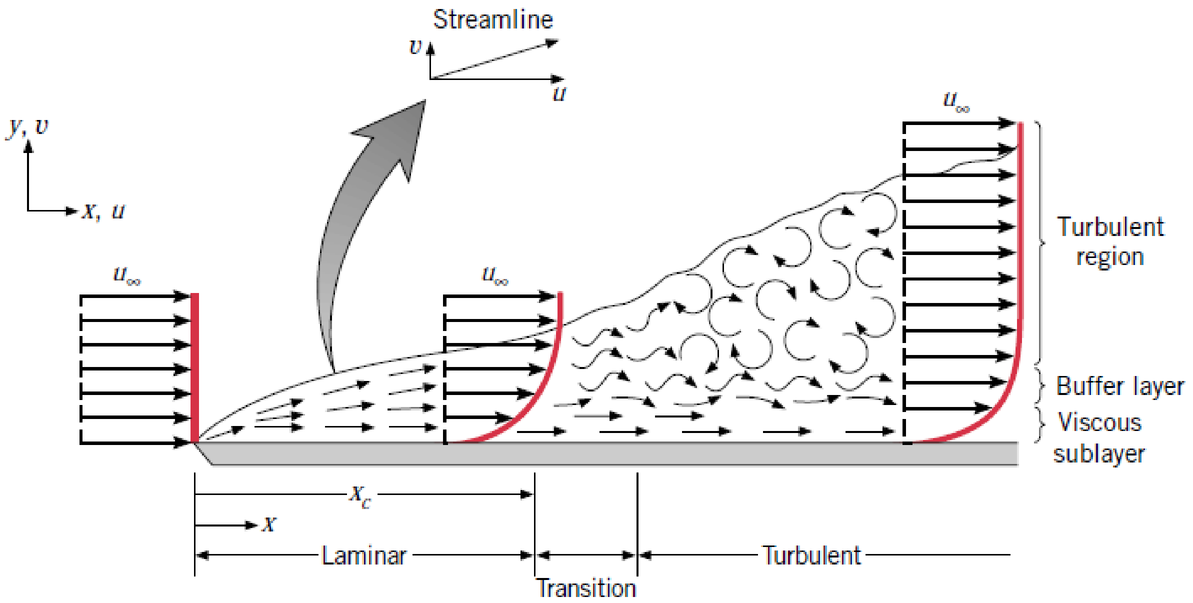


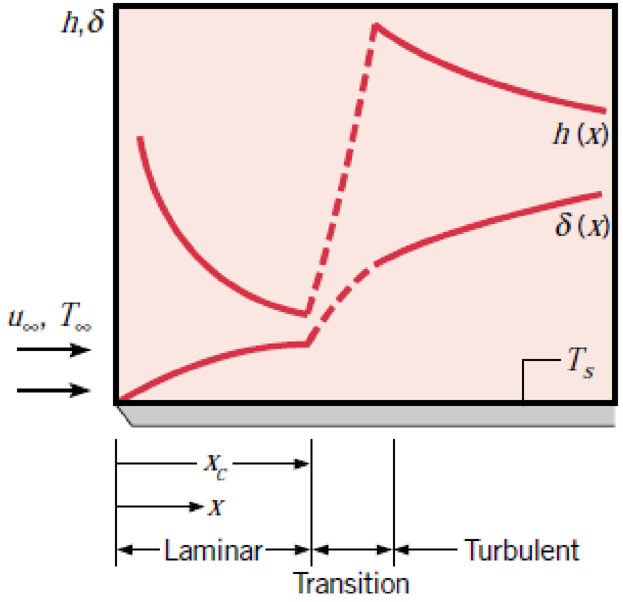


# Digital Tracking Calorimeter(DTC)

- **Heat transfer between layers**

Feasibility of air cooling convection system





Air gap sensitivity analysis → Boundary layer interaction

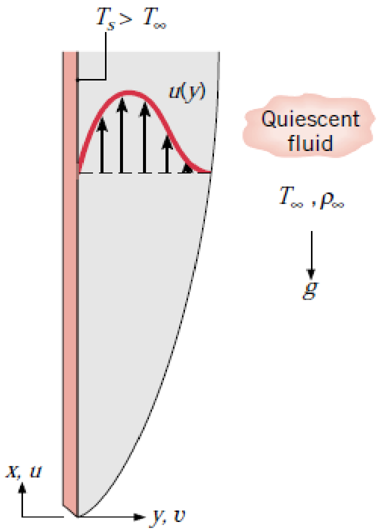
Convection heat transfer rate, thermal gradient in air between layers

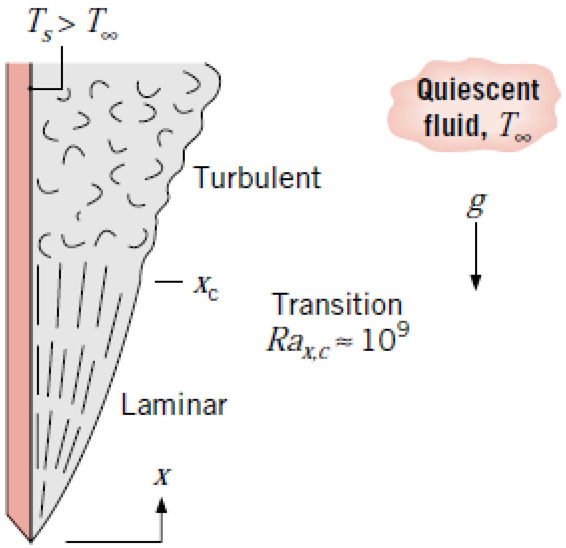
# Digital Tracking Calorimeter(DTC)

- **Feasibility of various Convection heat transfer:**
  - **Force convection** **q= hA ΔT**
    - Reynolds Number(Re)- ratio of inertia to viscous force-
    - Nusselt Number(Nu) – Thermal Boundary layer to velocity boundary laye
  - **Free/Natural convection**

    1: Laminar Flow
    - Bouyancy Forces
    - Volumetric thermal expansion coeficient (β)
    - Nusselt Number(Nu) Nu=f(Gr,Pr) = $\frac{3}{4}\left(\frac{Gr_x}{4}\right)^{\frac{1}{4}} g(Pr)$
    - Grashof Number (Gr) Prandtle Number (Pr)

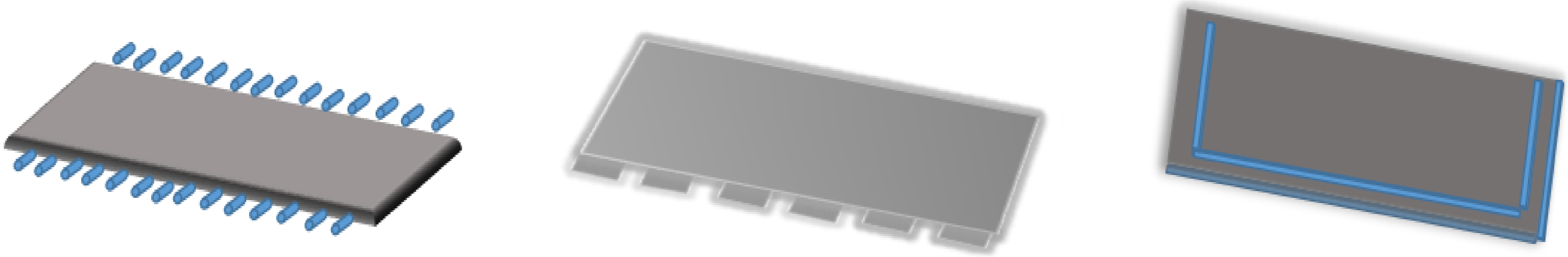
    2: Turbulence Flow
    - Bouyancy Forces
    - Volumetric thermal expansion coeficient (β)
    - Nusselt Number(Nu) Nu=f(Ra,Pr) = $\left\{\{0.825+\frac{0.387Ra^{\frac{1}{6}}}{\left[1+\left({}^{0.492}/_{Pr}\right)^{9/16}\right]^{8/27}}\right\}^2$
    - Rayleigh Number (Ra)
    - Prandtle Number (Pr)
    - Thermal Diffusivity (α)



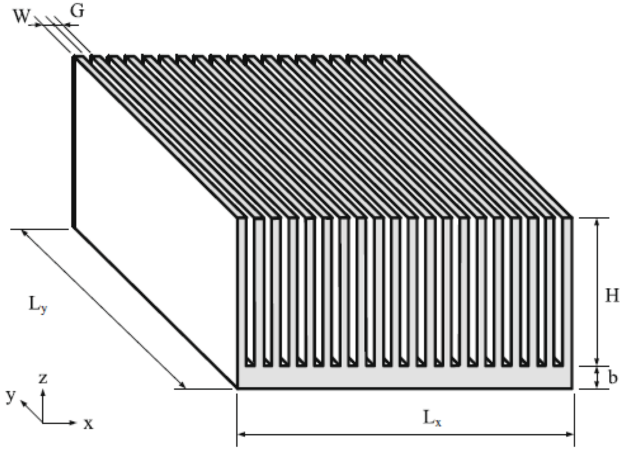


# Digital Tracking Calorimeter(DTC)

- Feasibility of ventilation between layers and surroundings of the calorimeter box
- Feasibility of micro bodies (e.g rectangular or cylindrical) pin on the absorber edges as heat sink to increase convection heat transfer rate



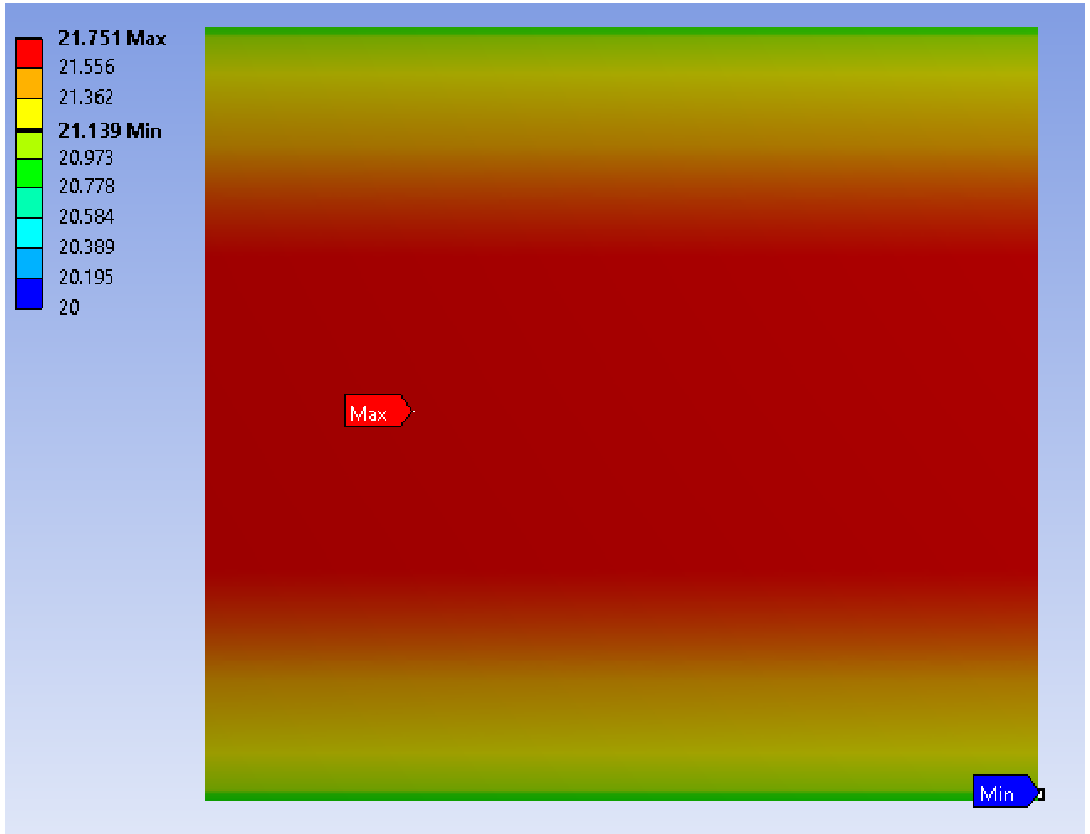
- Dual purpose design for calorimeter structure, with opportunity to work as support structure or stave rack & also heat sink



# Digital Tracking Calorimeter(DTC)

- **Simulation result for single stave layer – 1st scenario chip set up-**
  - free convection
  - 300 mW/Cm2 heat generation
  - Laminar air/water cooling(T=10, V=1m/s)
  - Ambient Temperature 22

Max Temp.
in absorber plate
~ 21.7°C

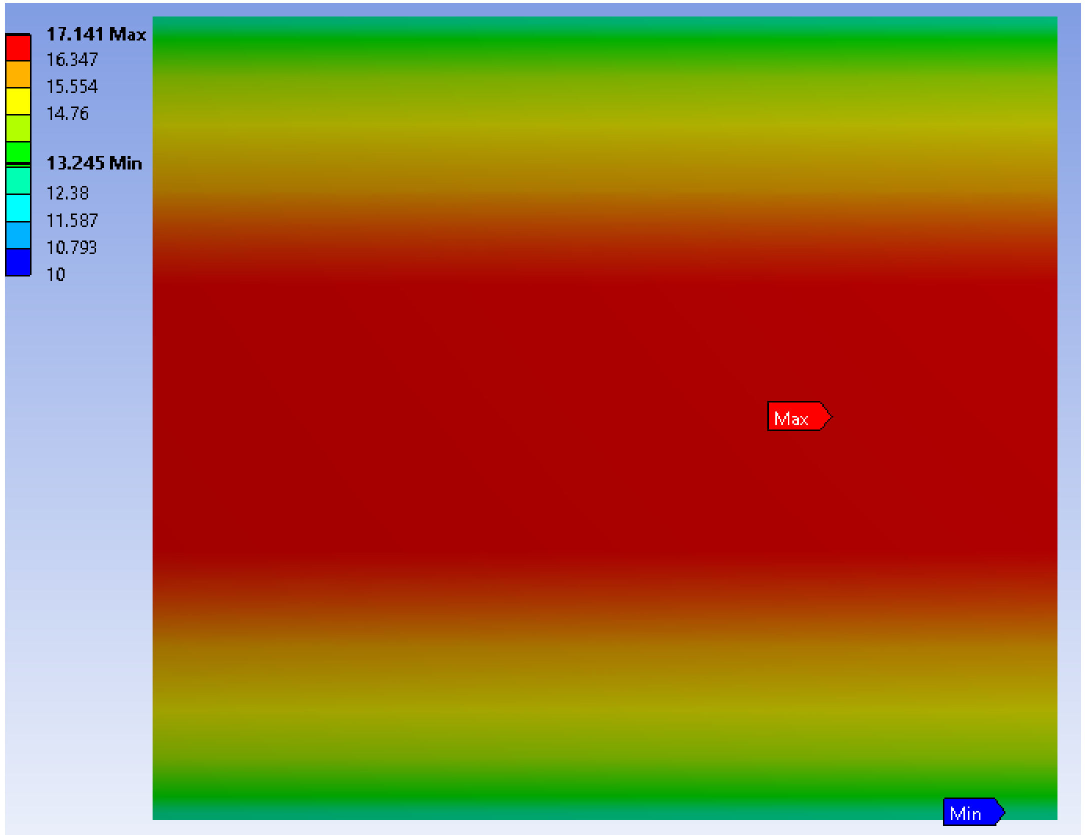


**Tem. Distribution**

**Air cooling**

**Water cooling**

Max Temp. in absorber
plate
~ 17.1°C



# Digital Tracking Calorimeter(DTC)

- **Simulation result for single stave layer – 1st scenario chip set up-**

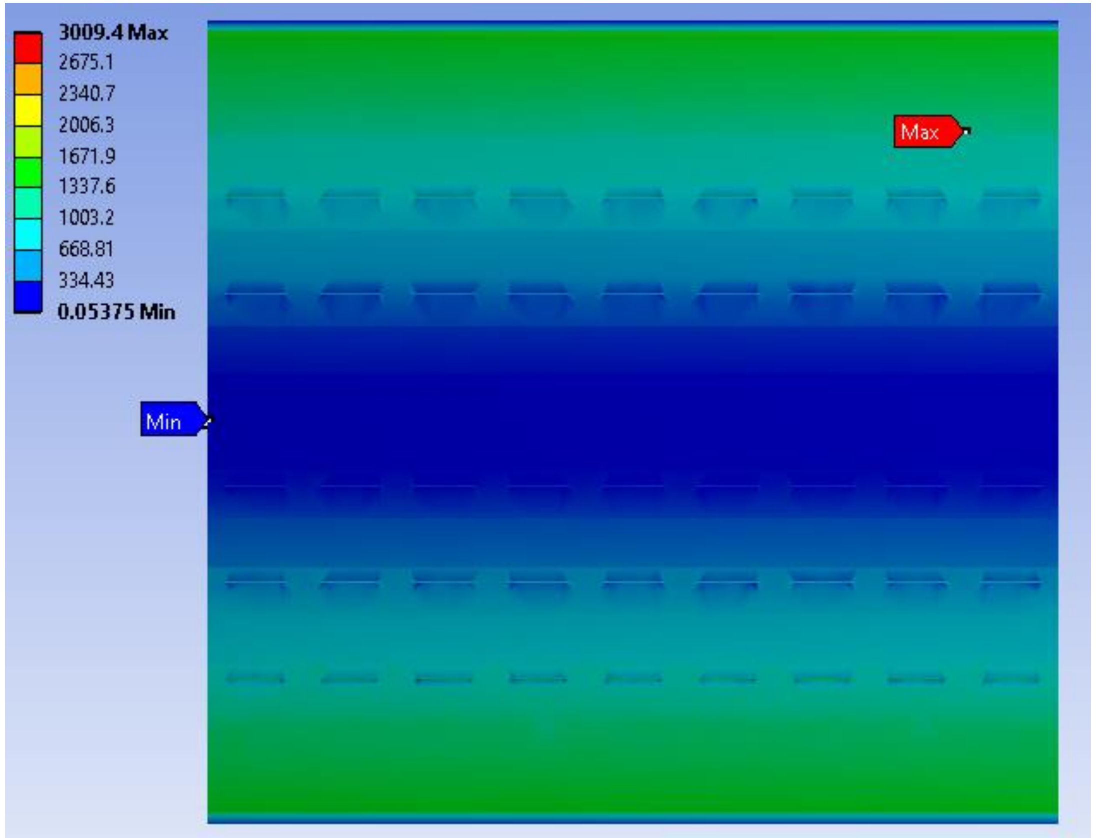
➡ free convection

➡ 300 mW/Cm2 heat generation

➡ Laminar air/water cooling(T=10, V=1m/s)

➡ Ambient Temperature 22

Max Heat flux
~ 3009 W/m2

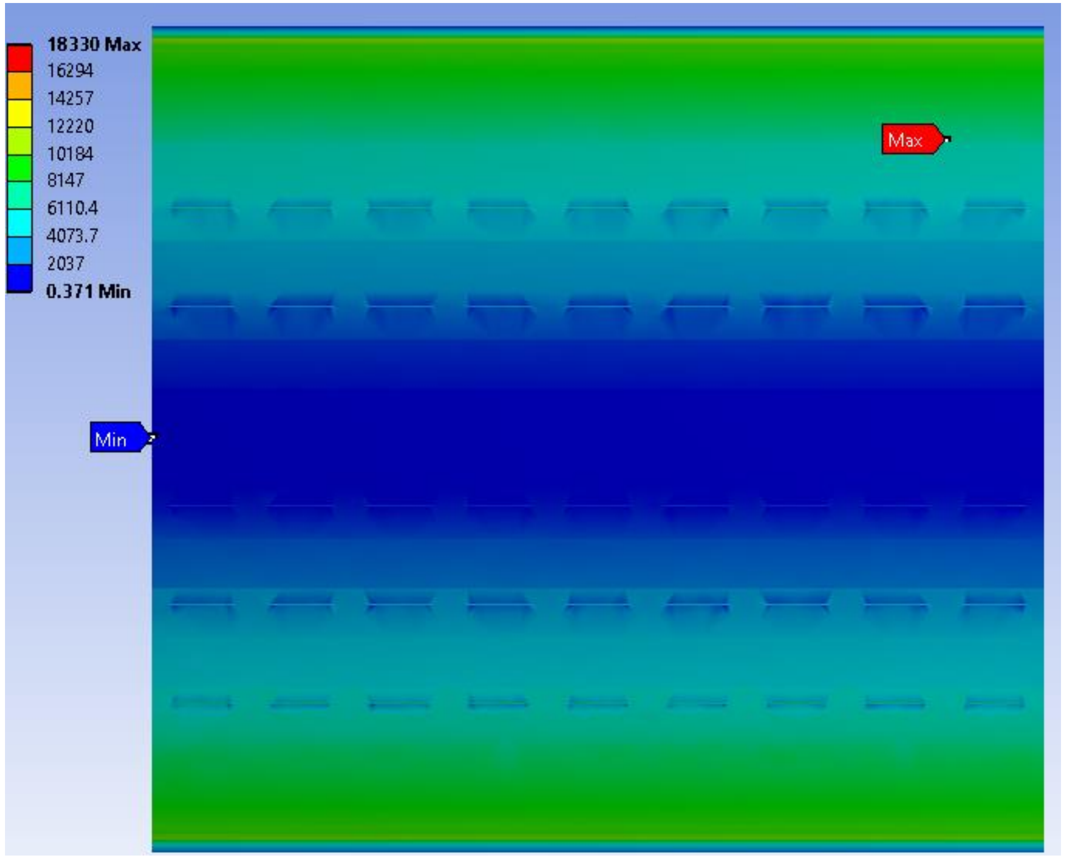


**Heat Flux**

⬅ **Air cooling**

**Water cooling** ➡

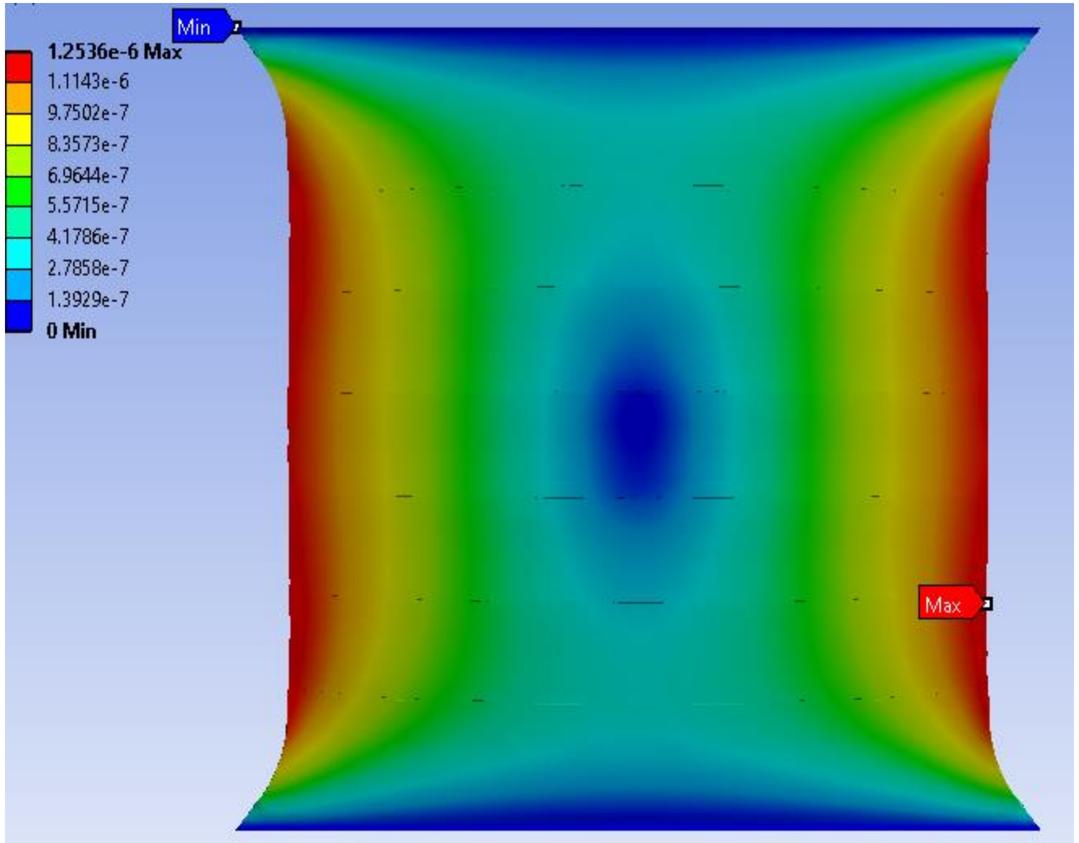
Max Heat flux
~ 18330 W/m2



# Digital Tracking Calorimeter(DTC)

- **Simulation result for single stave layer – 1st scenario chip set up-**
  - free convection
  - 300 mW/Cm2 heat generation
  - Laminar air/water cooling(T=10, V=1m/s)
  - Ambient Temperature 22

Max deformation in layer
~ 1.25e-6 m

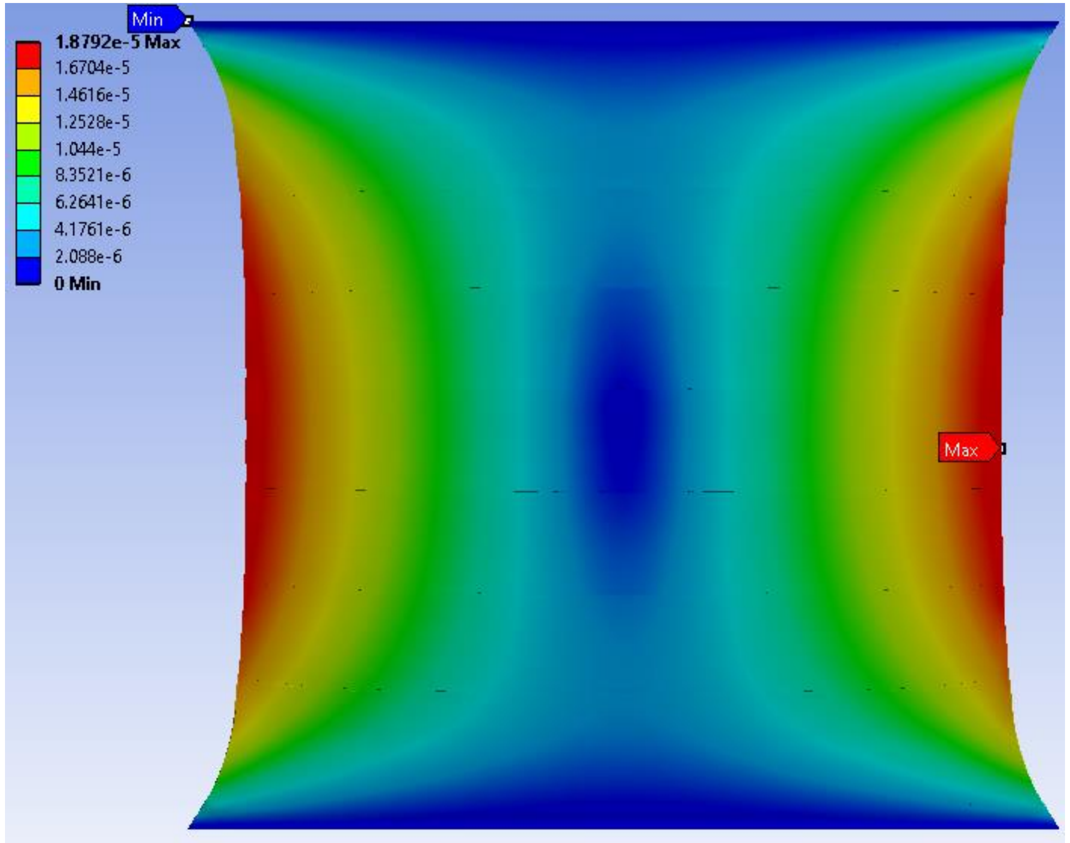


**Deformation**

← **Air cooling**

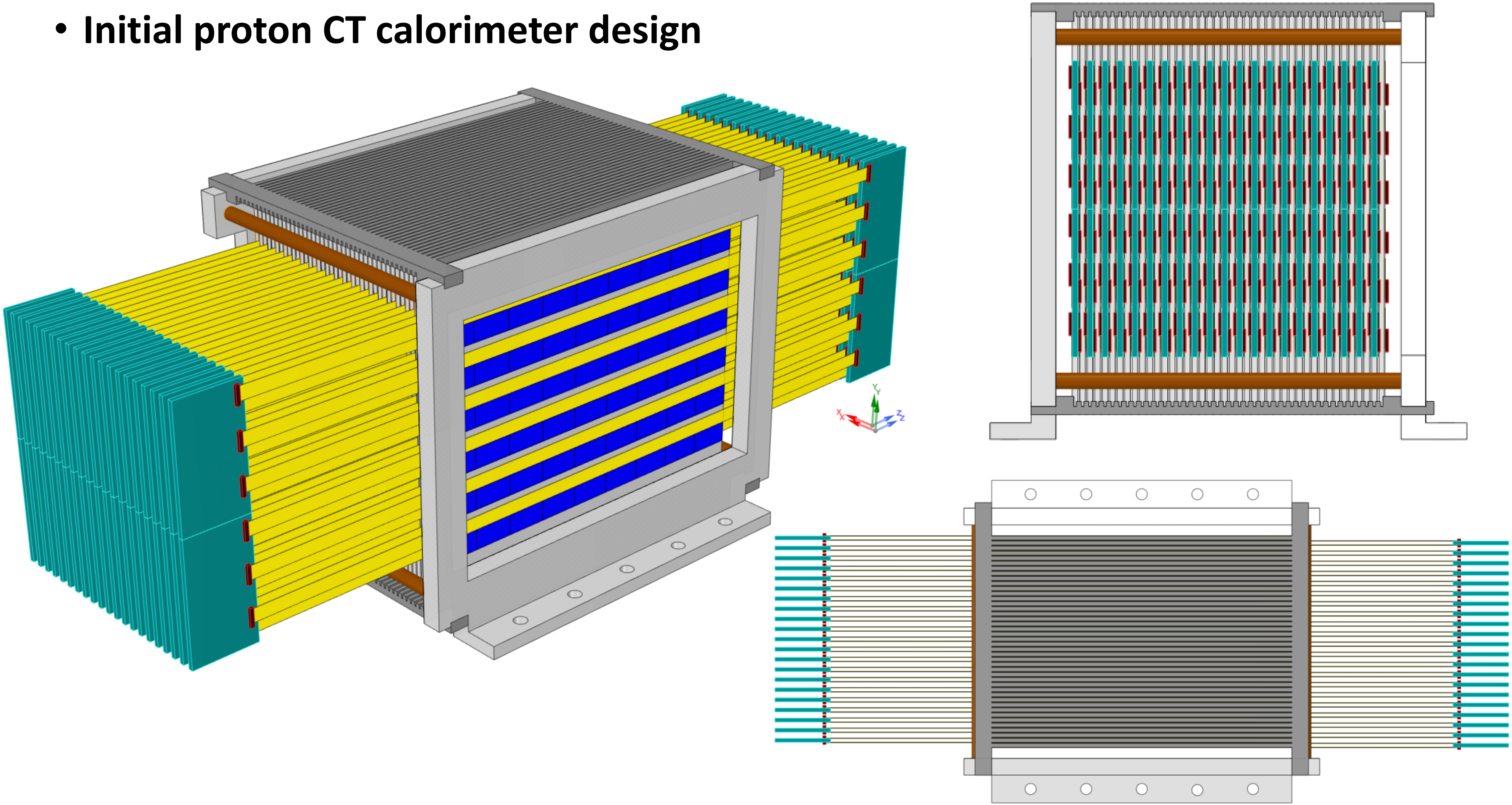
**Water cooling** →

Max deformation in layer
~ 1.87e-5 m



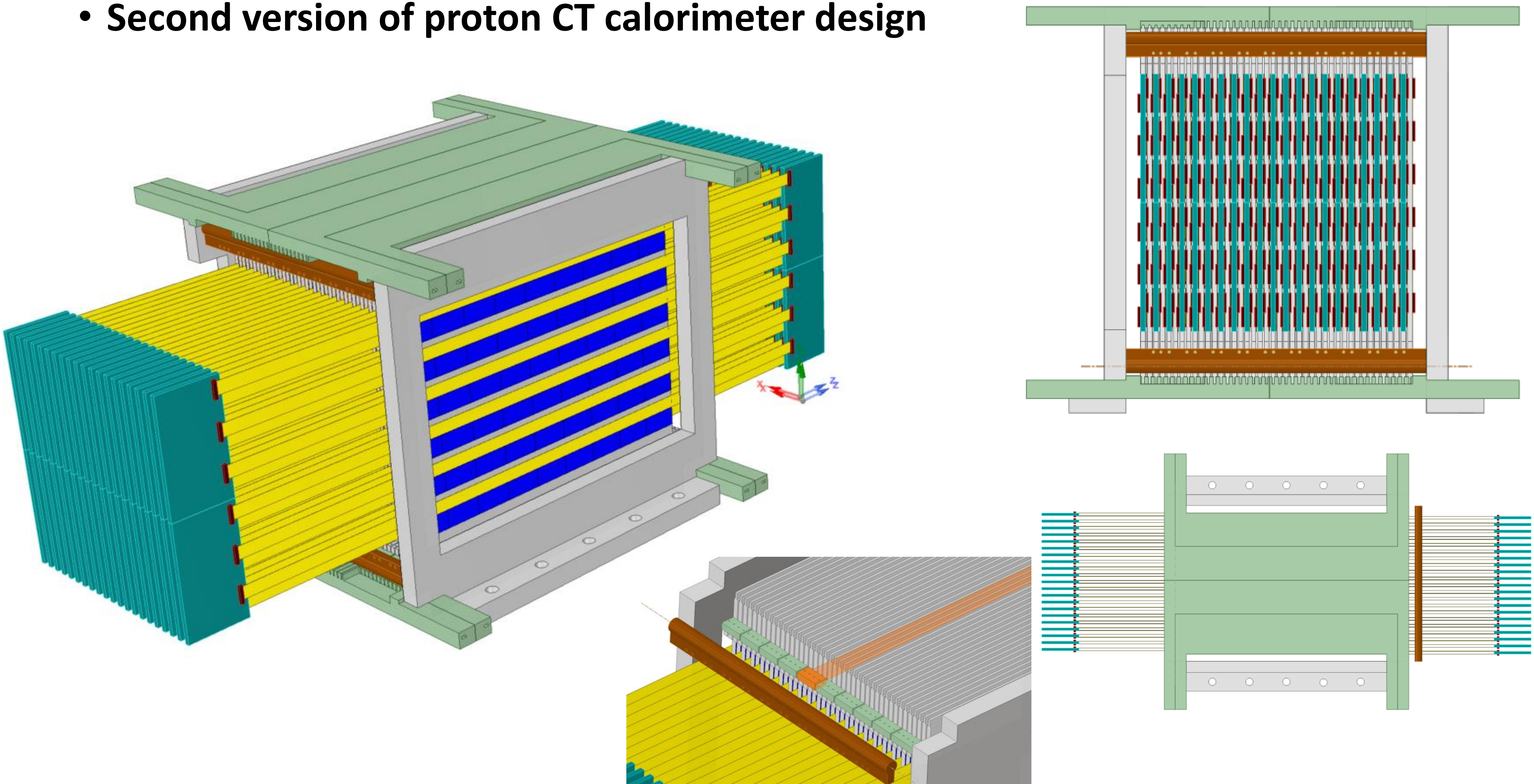
# Digital Tracking Calorimeter(DTC)

- **Initial proton CT calorimeter design**



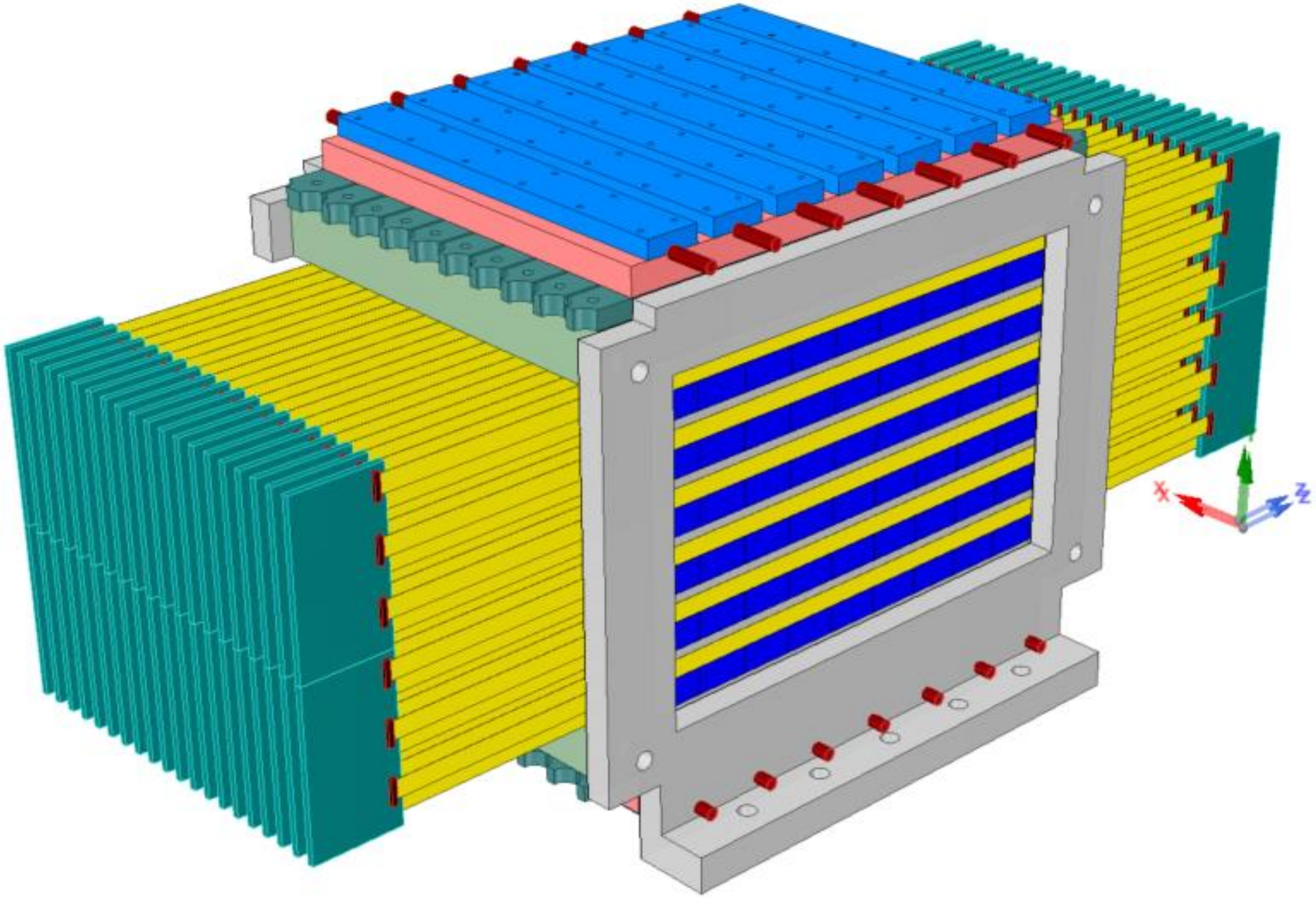
# Digital Tracking Calorimeter(DTC)

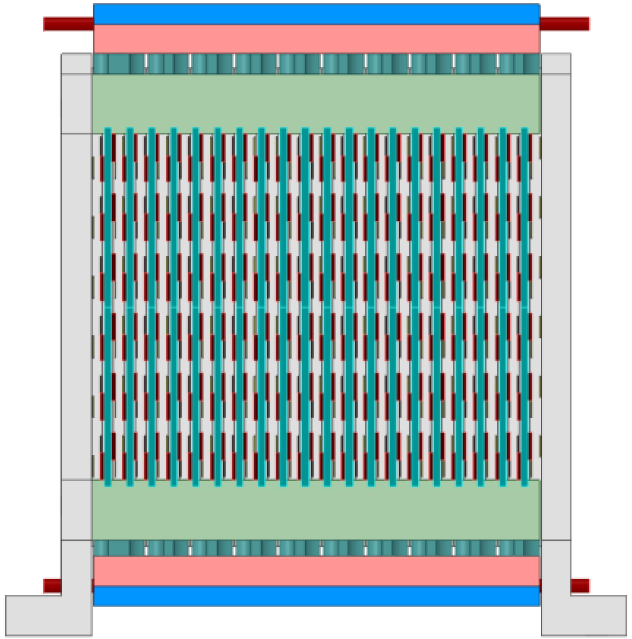
- **Second version of proton CT calorimeter design**

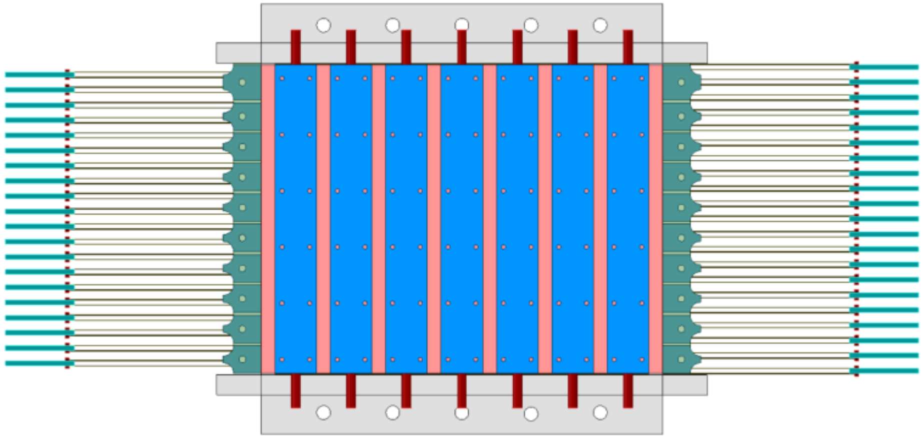


# Digital Tracking Calorimeter(DTC)

- **Third(latest) version of proton CT calorimeter design**







# Digital Tracking Calorimeter(DTC)

- **Simulation result for single stave layer – 1st scenario chip set up/ latest design (3rd revision)-**

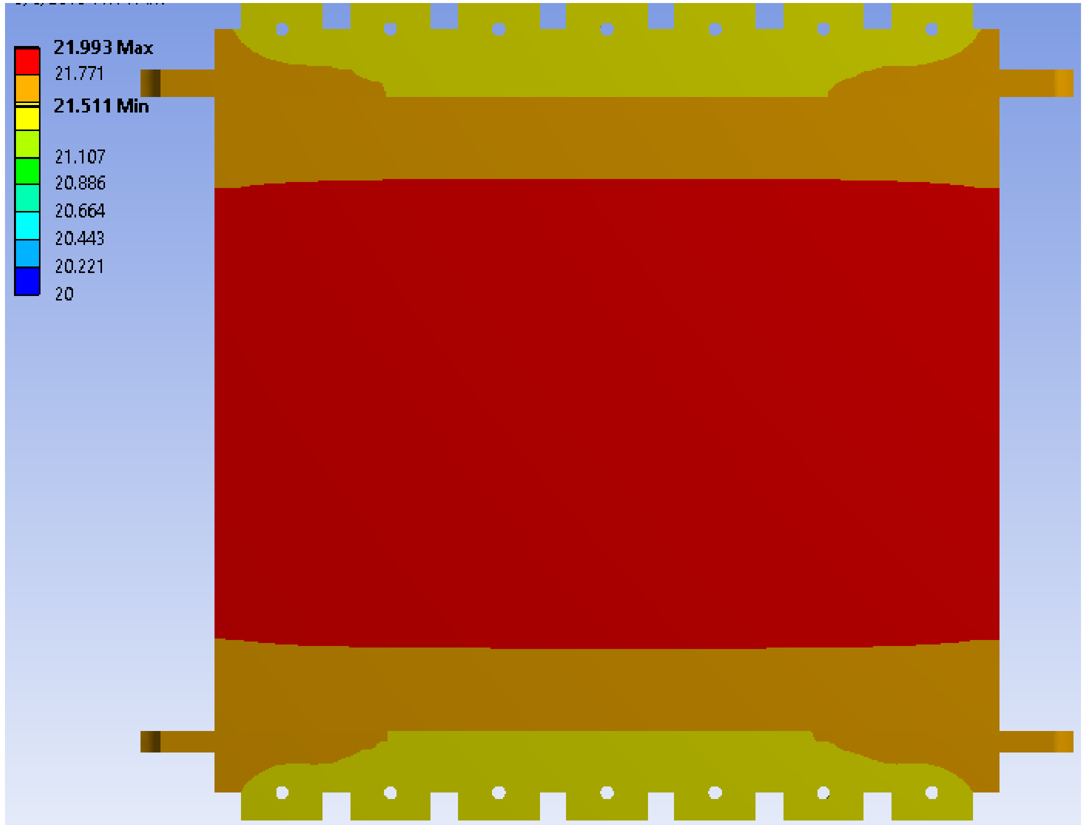
➡ free convection

➡ 300 mW/Cm2 heat generation

➡ Laminar air/water cooling(T=10, V=1m/s)

➡ Ambient Temperature 22

Max Temp.
in absorber plate
~ 21.9°C

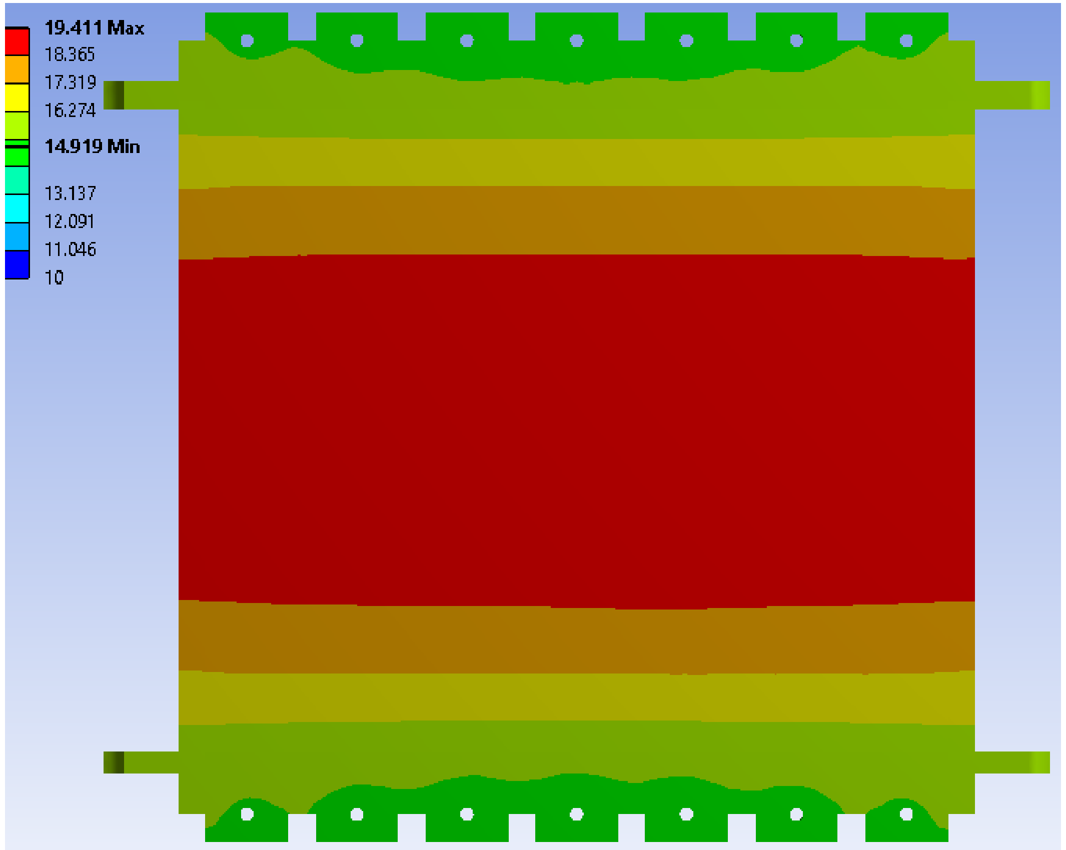


**Tem. Distribution**

⬅ **Air cooling**

**Water cooling** ➡

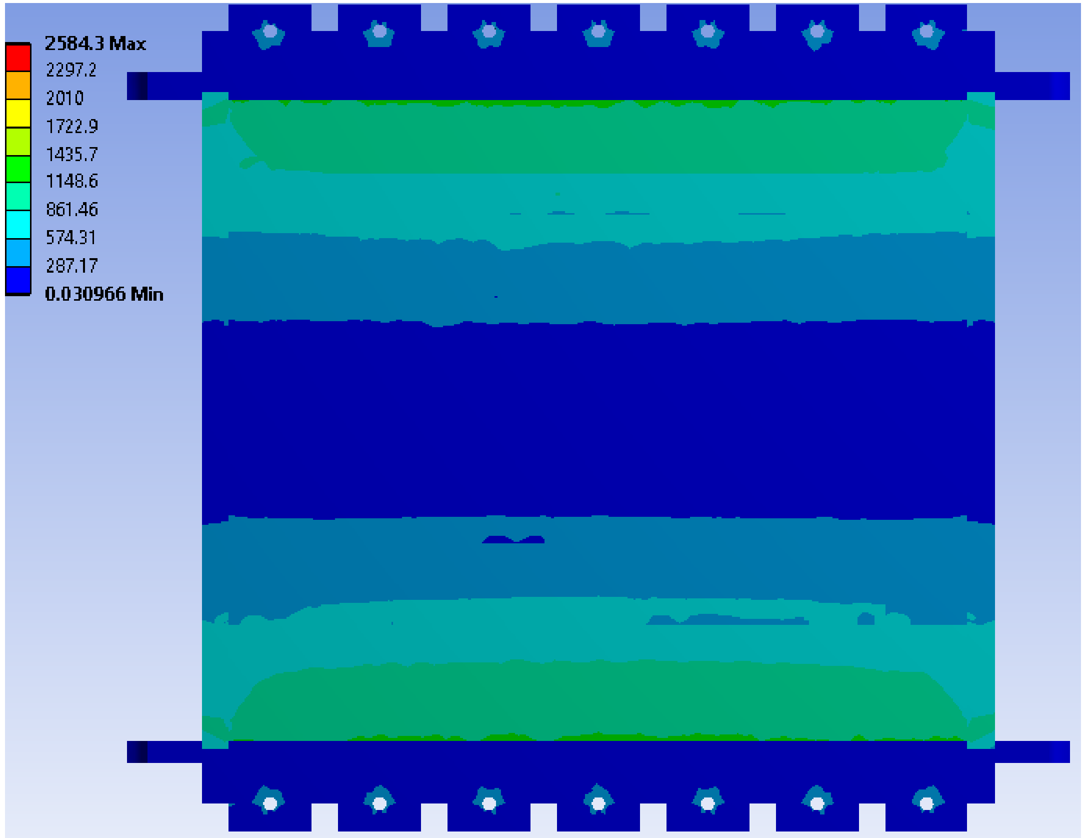
Max Temp. in absorber plate
~ 19.4°C



# Digital Tracking Calorimeter(DTC)

- **Simulation result for single stave layer – 1st scenario chip set up/ latest design (3rd revision)-**
  - free convection
  - 300 mW/Cm2 heat generation
  - Laminar air/water cooling(T=10, V=1m/s)
  - Ambient Temperature 22

Max Heat flux
~ 2584 W/m2

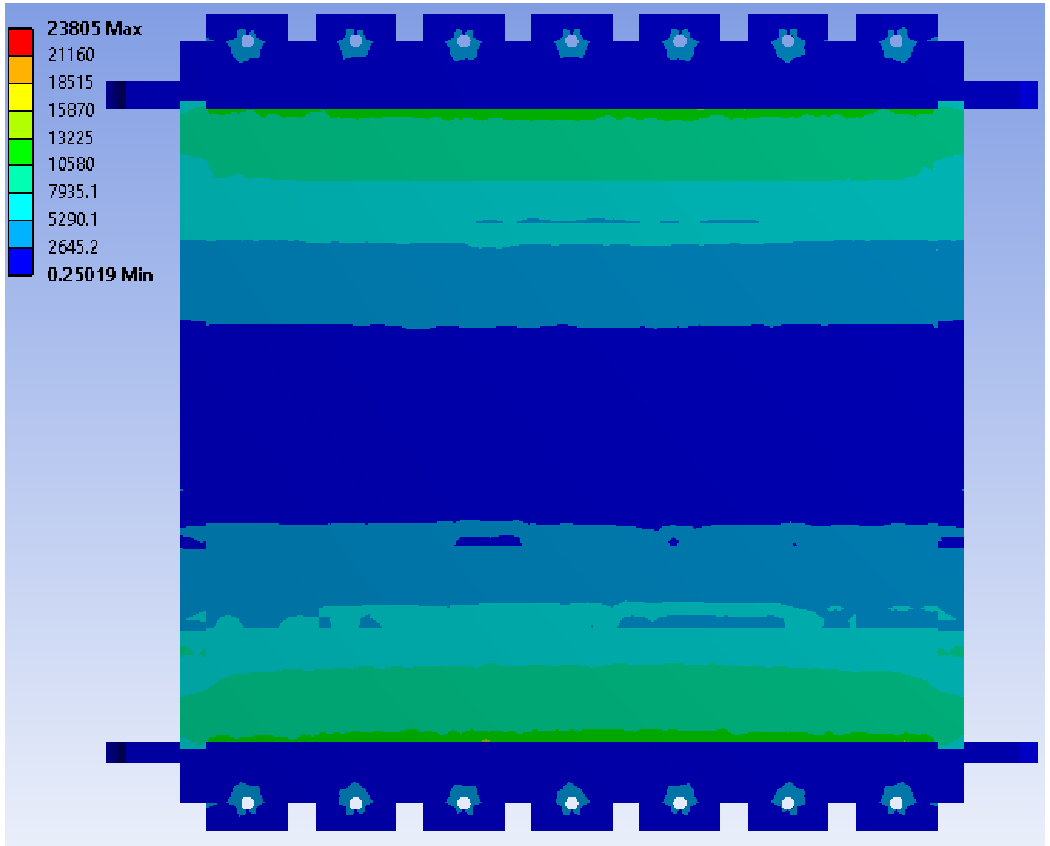


**Heat Flux**

**Air cooling**

**Water cooling**

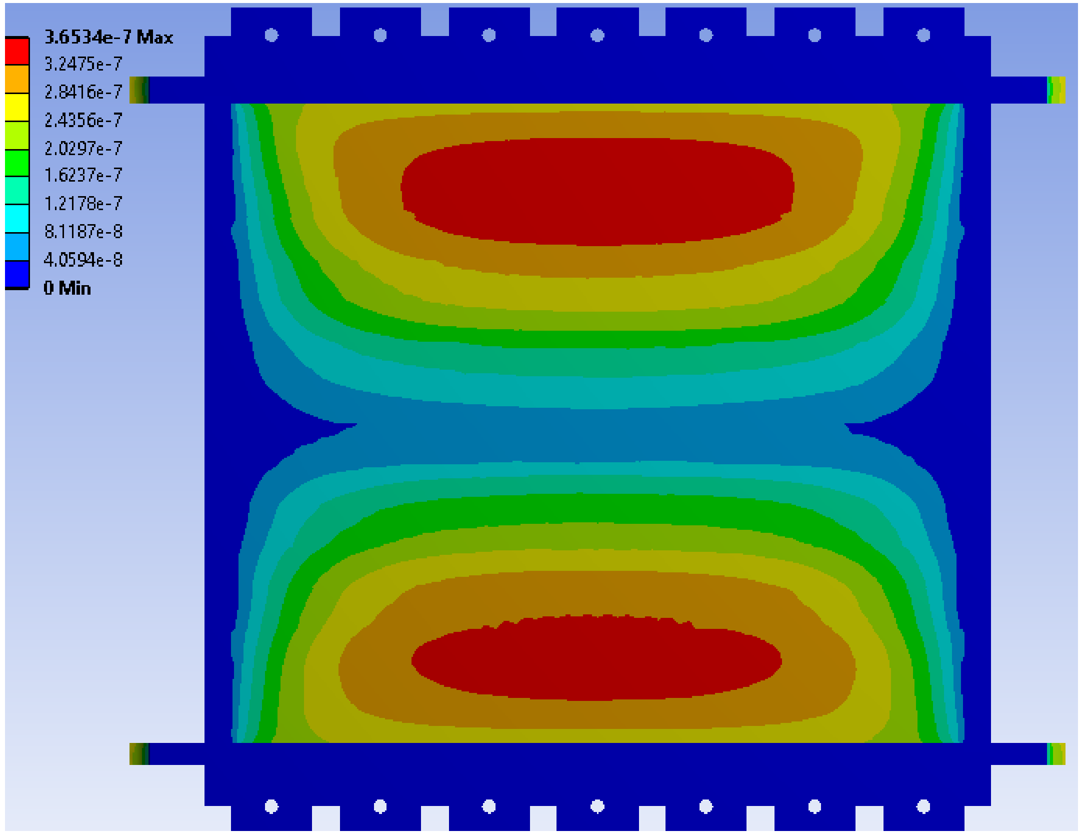
Max Heat flux
~ 23805 W/m2



# Digital Tracking Calorimeter(DTC)

- **Simulation result for single stave layer – 1st scenario chip set up/ latest design (3rd revision)-**
  - ➡ free convection
  - ➡ 300 mW/Cm2 heat generation
  - ➡ Laminar air/water cooling(T=10, V=1m/s)
  - ➡ Ambient Temperature 22

Max deformation in layer
~ 3.65e-7 m

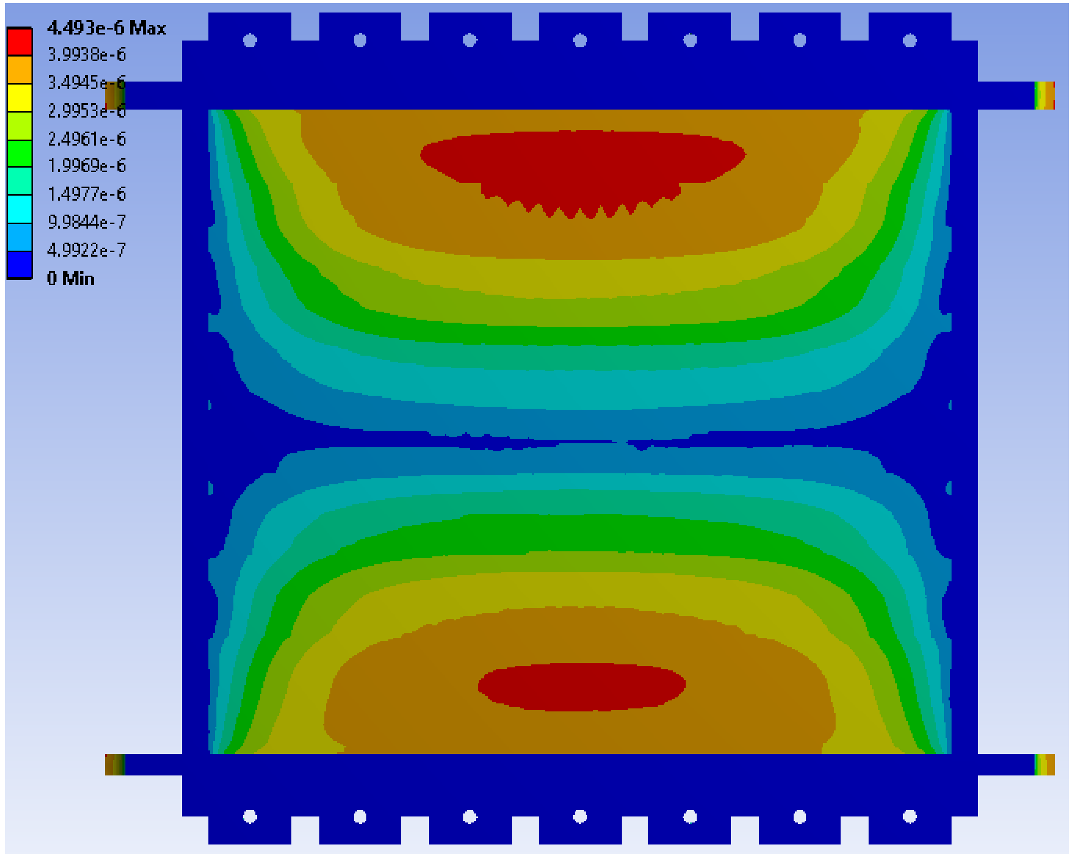


**Deformation**

⬅ **Air cooling**

**Water cooling** ➡

Max deformation in layer
~ 4.49e-6 m



# Digital Tracking Calorimeter(DTC)

- **Simulation result for 5 layers –latest design (3rd revision)-**

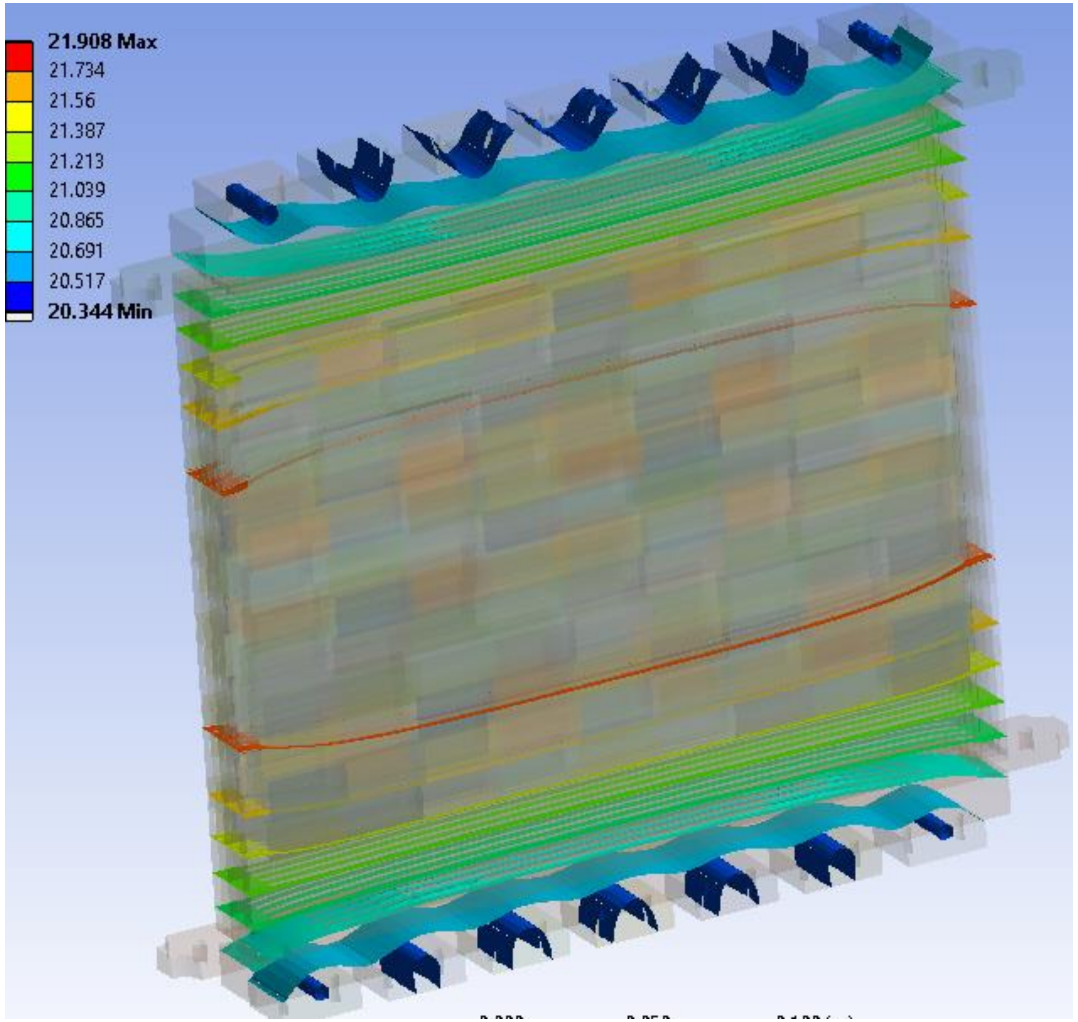
➡ free convection

➡ 300 mW/Cm2 heat generation

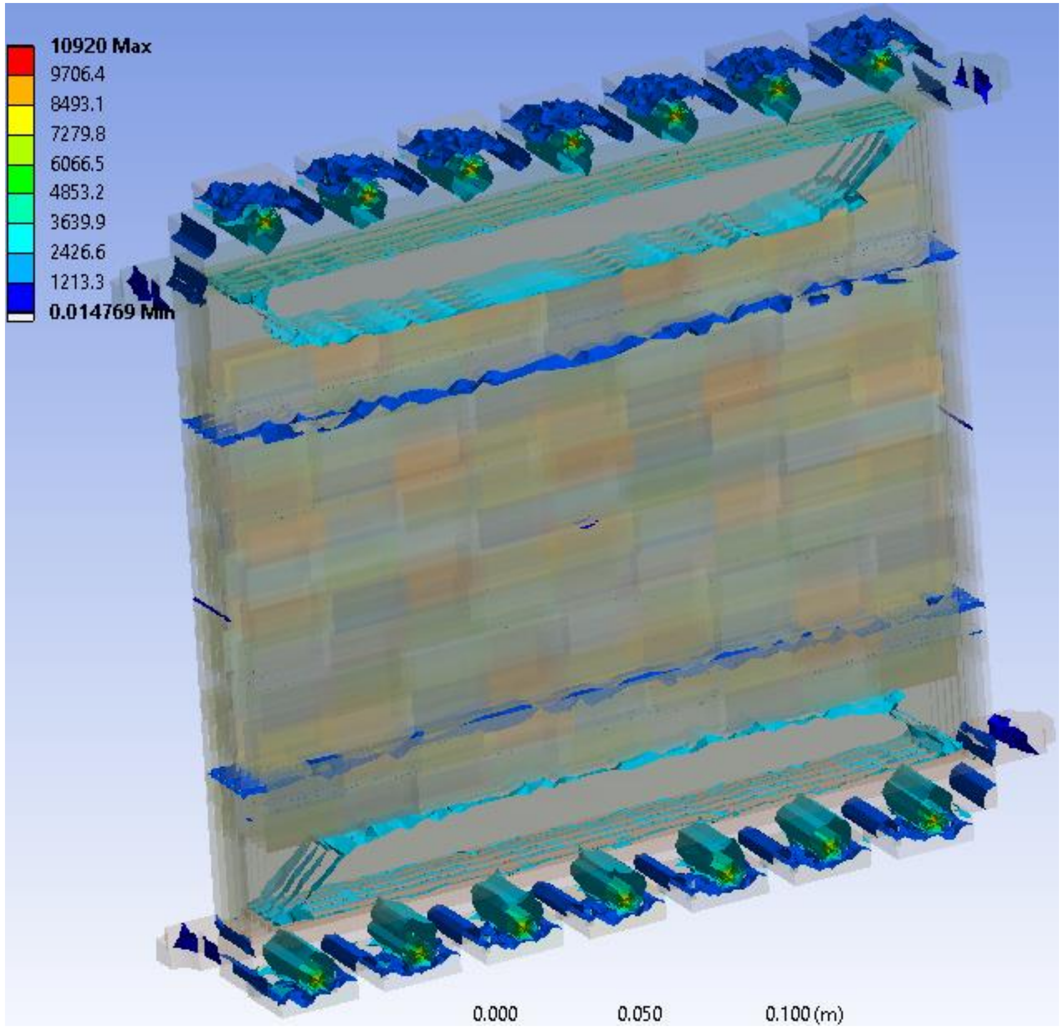
➡ Laminar water cooling(T=10, V=1m/s)

➡ Ambient Temperature 22

Temperature distribution

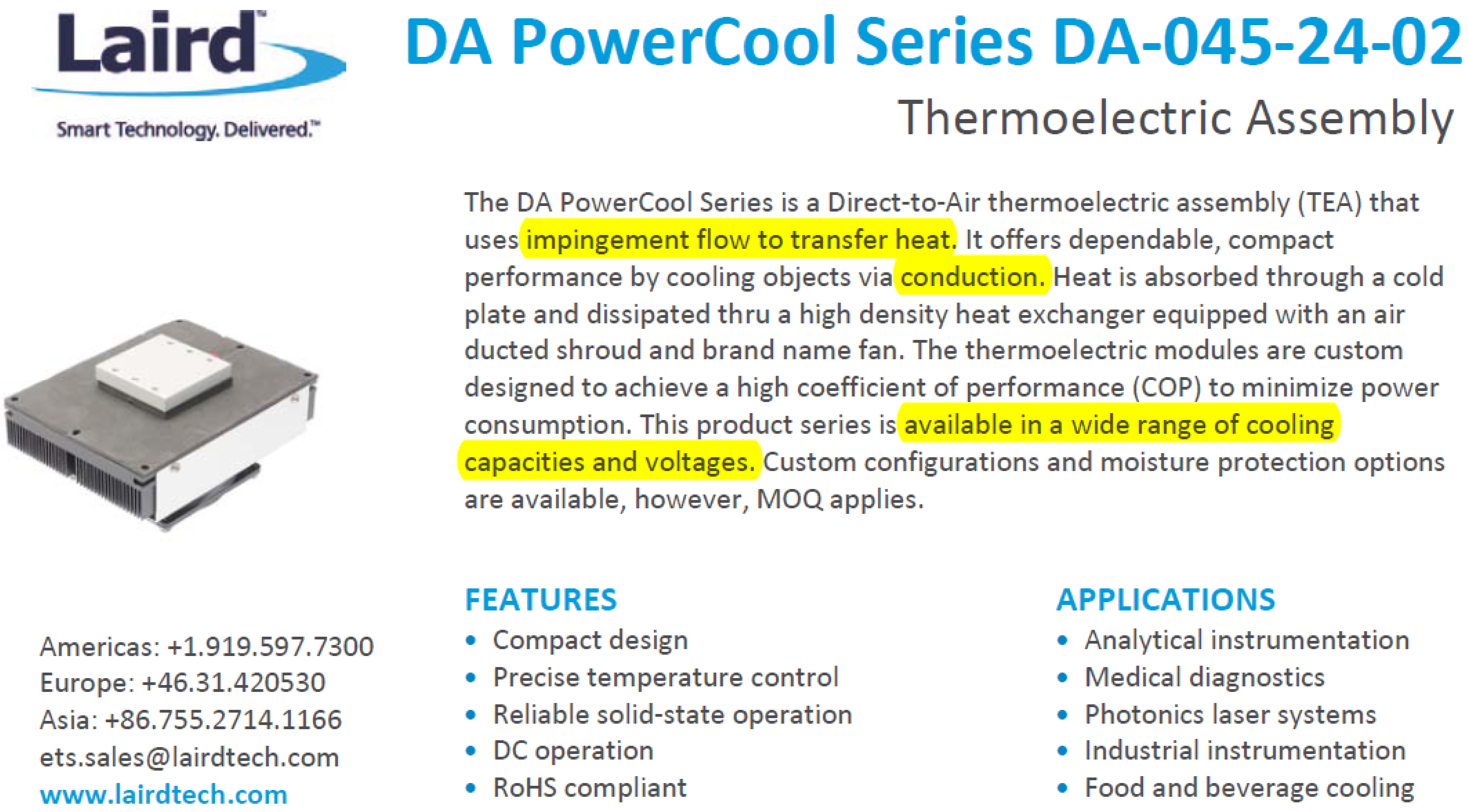


Heat Flux (W/m2)



# Digital Tracking Calorimeter(DTC)

## Different cooling schem!?



Laird

Smart Technology. Delivered.™

# DA PowerCool Series DA-045-24-02

## Thermoelectric Assembly

The DA PowerCool Series is a Direct-to-Air thermoelectric assembly (TEA) that uses impingement flow to transfer heat. It offers dependable, compact performance by cooling objects via conduction. Heat is absorbed through a cold plate and dissipated thru a high density heat exchanger equipped with an air ducted shroud and brand name fan. The thermoelectric modules are custom designed to achieve a high coefficient of performance (COP) to minimize power consumption. This product series is available in a wide range of cooling capacities and voltages. Custom configurations and moisture protection options are available, however, MOQ applies.

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www.lairdtech.com

### FEATURES

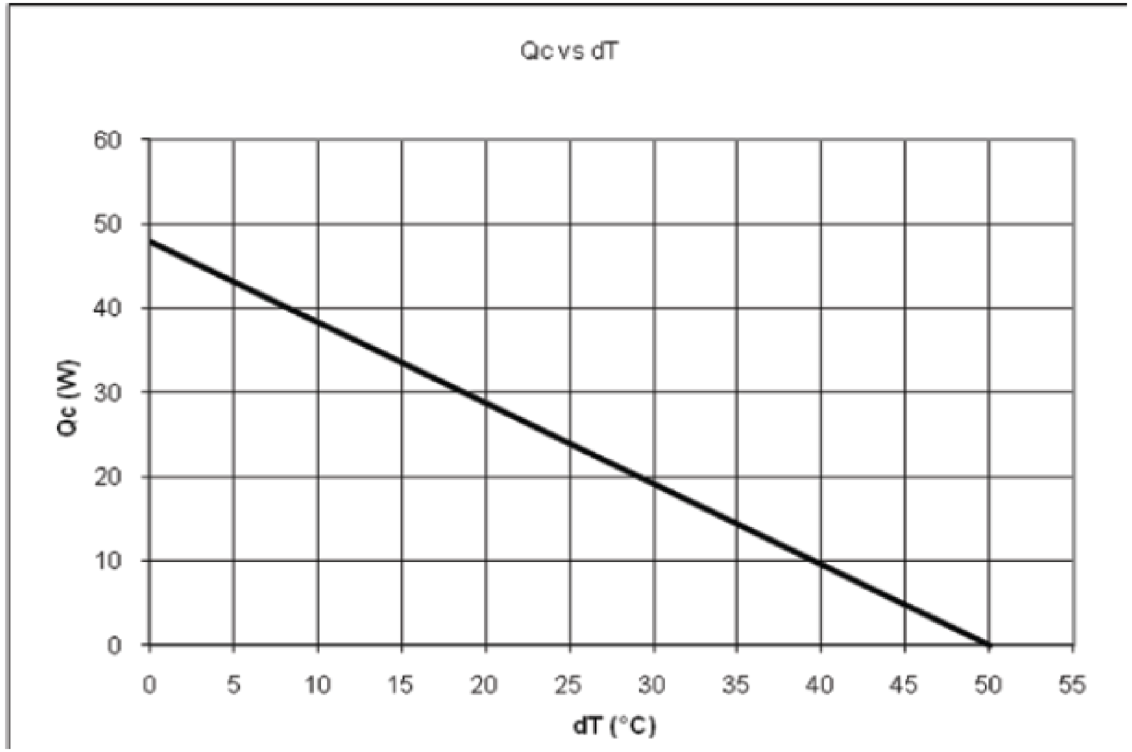
- Compact design
- Precise temperature control
- Reliable solid-state operation
- DC operation
- RoHS compliant

### APPLICATIONS

- Analytical instrumentation
- Medical diagnostics
- Photonics laser systems
- Industrial instrumentation
- Food and beverage cooling

| SPECIFICATIONS | |
|---|---|
| Cooling Power Qcmax (W) | 48 |
| Running Current (A) | 2.5 |
| Startup Current (A) | 3.5 |
| Nominal Voltage (V) | 24 |
| Max Voltage (V) | 30 |
| Power Input (W) | 60 |
| Operating Temperature (°C) | -10 to 46 |
| Weight (kg) | 1.2 |
| MTBF (fans – hrs) | 50,000 |
| Performance Tolerance | ±10% |

## PERFORMANCE CURVE



# Questions?