Simulation studies of the technical prototype for the Mu3e Tile Detector

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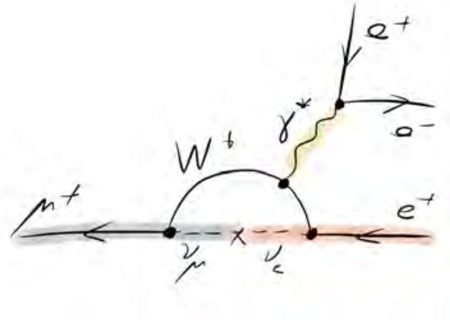
HighRR

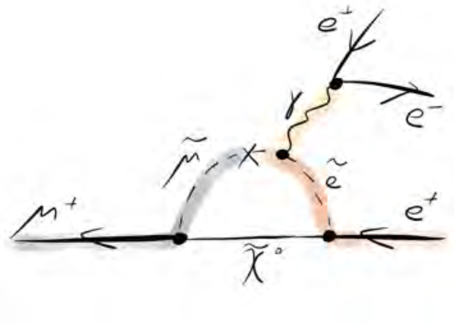
The decay $\mu \to eee$

- **lepton flavour violating (LVF) decay**
- Standard Model:
  - → via neutrino oscillation
  - → suppressed by more than O(10^{-54})



The decay $\mu \rightarrow eee$

- **lepton flavour violating (LVF) decay**
- Standard Model:
  - $\rightarrow$ via neutrino oscillation
  - $\rightarrow$ suppressed by more than O(10^{-54})
- observation would be sign of new physics
- current limit: BR $< 10^{-12}$ by the SINDRUM experiment



Background sources

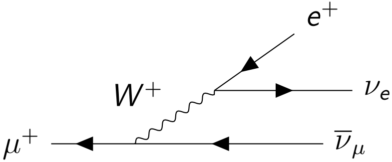
two types of background sources:

1) **internal conversion:**

   → $\mu \rightarrow eee\nu\nu$

   → veto via reconstruction of missing neutrino energy

   → excellent momentum resolution needed



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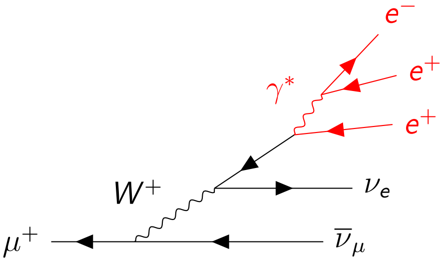

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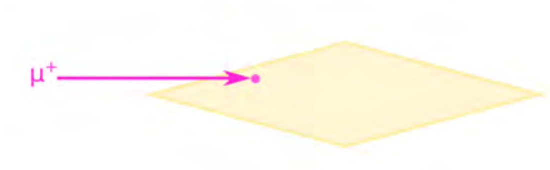
2) **accidental background:**

→ muon decay + electron-positron scattering

→ veto via precise vertex and **time** determination



[scheme by Frank Meier Aeschbacher]

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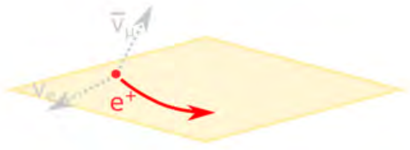

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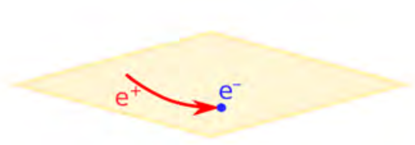

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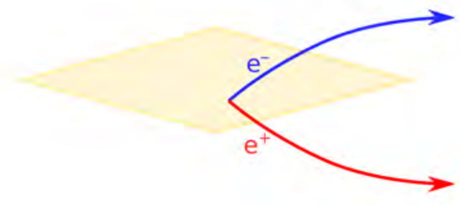

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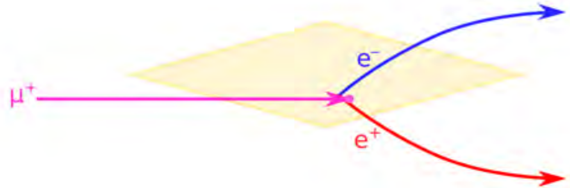

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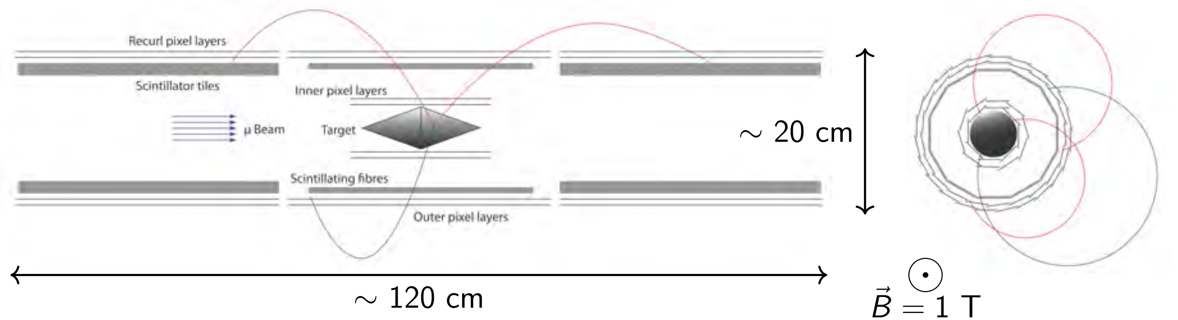
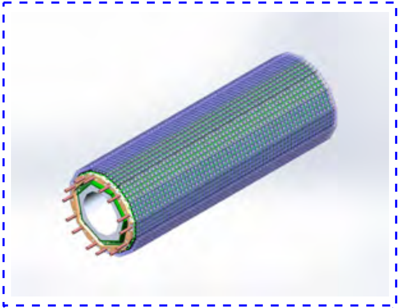
The Mu3e experiment

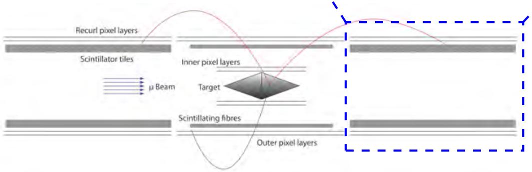
- target sensitivity $\leq O(10^{-16})$
  - → pixel detectors: tracking, vertexing
  - → scintillating fibre (SciFi) Detector and **Tile Detector**: **timing**
- fixed target experiment
  - → to be installed at PSI, Switzerland



The Tile Detector

- to be installed on recurl stations (up- and downstream of target)
- **requirements:**
  - → time resolution $<$ **100 ps**
  - → detection efficiency $\sim$ 100%
  - → hit rate up to 60 kHz per channel
- scintillating tiles and silicon photomultipliers (SiPMs)





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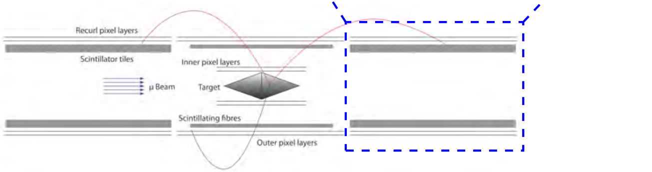

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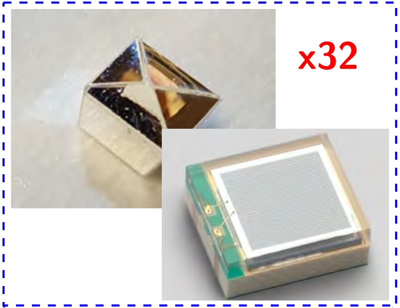

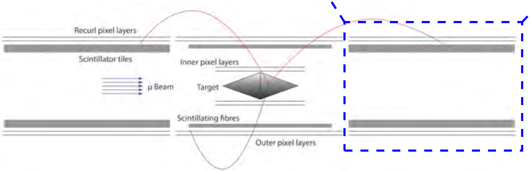

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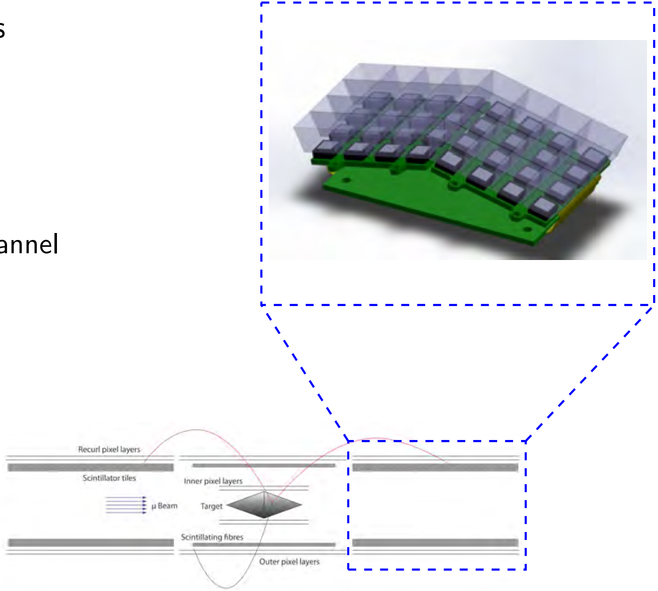

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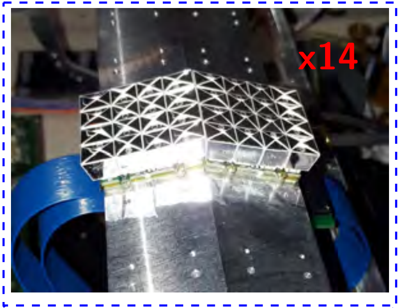

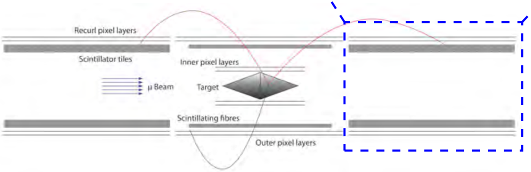

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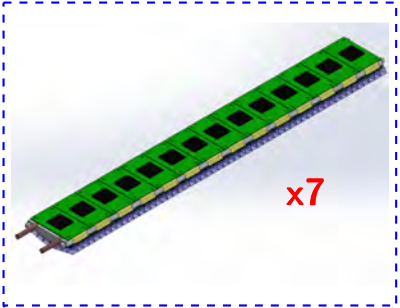

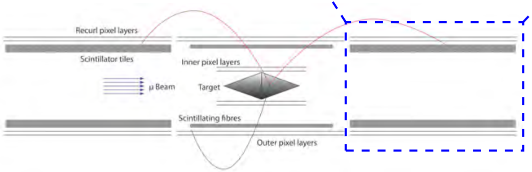

The Tile Detector

- to be installed on recurl stations (up- and downstream of target)
- **requirements:**
  - → time resolution < **100 ps**
  - → detection efficiency ∼ 100%
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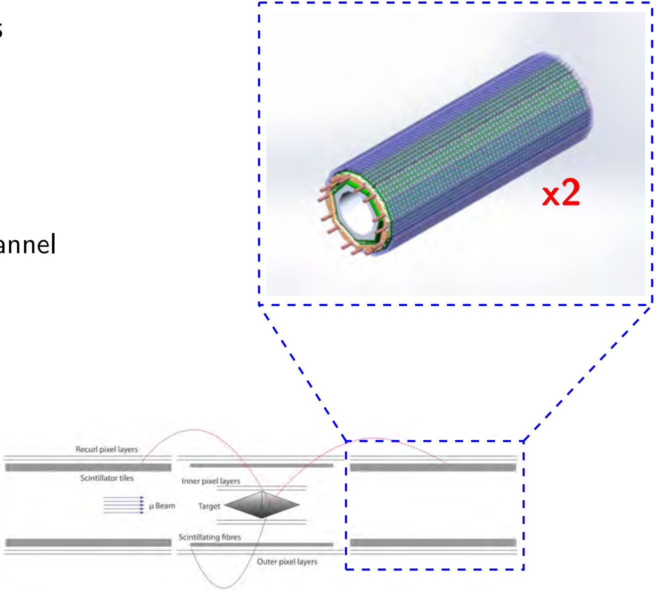
- scintillating tiles and silicon photomultipliers (SiPMs)
- reduction of accidental background by factor 100



Thermal simulation - motivation

we want a **reliable thermal simulation** because:

1) Tile Detector surrounded by pixel detector
   - $\rightarrow$ cooled with helium $\Rightarrow$ heat gradient
   - $\rightarrow$ SiPM operation? ($\Rightarrow$ HV?)

2) integration of services (cooling pipes and ducts, cables, ...)
   - $\rightarrow$ check different geometries of Tile Detector
   - $\rightarrow$ test in simulations first

$\rightarrow$ **full detector simulation important to finalise design!**

Thermal simulation - strategy

idea:

- build simple setup in the lab
- try to replicate as close as possible in simulation
  - $\rightarrow$ geometry
  - $\rightarrow$ material (heat transfer, coupling between materials,...)
  - $\rightarrow$ environment

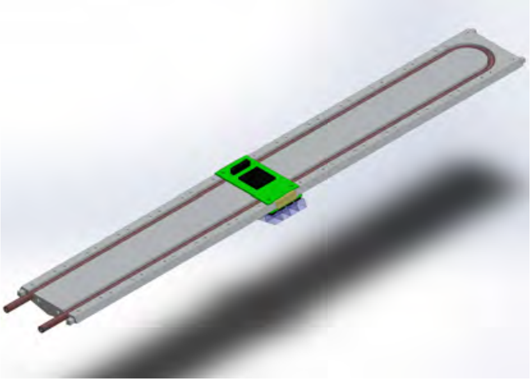
$\rightarrow$ **goal:** reliable simulation

$\rightarrow$ can be extended/modified

Thermal simulation - setup and input

- thermal simulation using 3D CAD software SolidWorks
  - → "Flow Simulation" add-in to model water and air flow
  - → finite element method
  - → takes care of material properties, heat exchange,...

- **ingredients:**
  - → cooling plate + pipe
  - → one submodule
  - → "box" of air → lab environment



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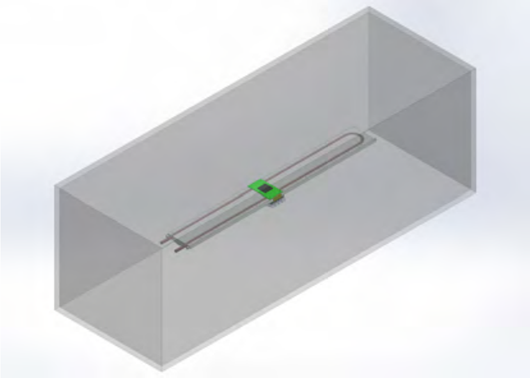

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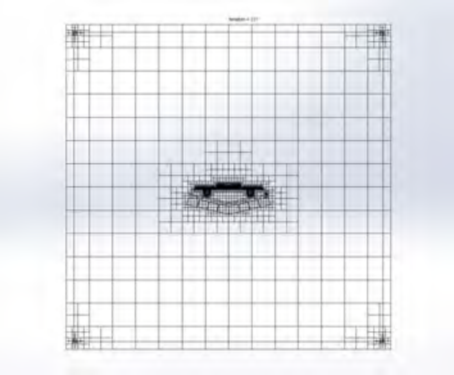
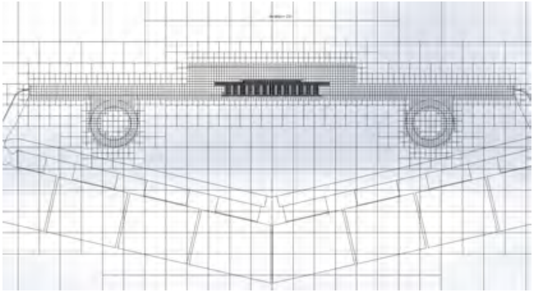
- **input from lab measurements:**
  - water temperature: 15°C
  - volume flow of water: 4.7 cm^3/s
  - environment temperature: 21°C
  - different chip power consumptions:
    - → $\sim$ 2.1 W
    - → $\sim$ 1.7 W
    - → $\sim$ 0.86 W

  ⇒ measurement of chip temperature

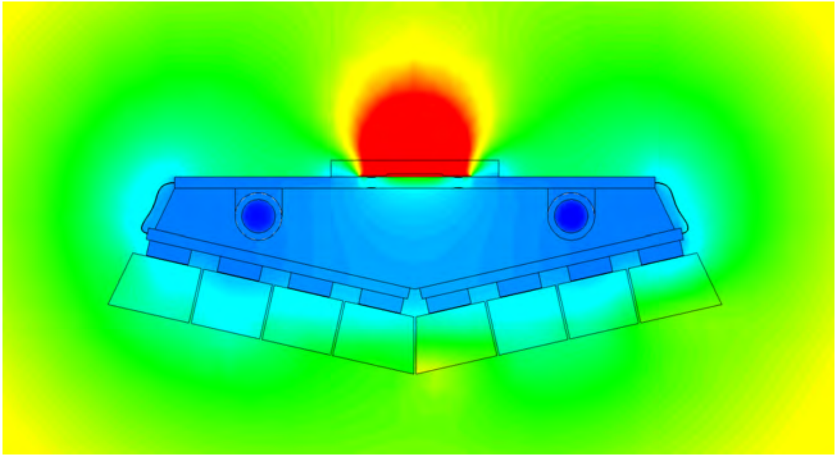
Meshing

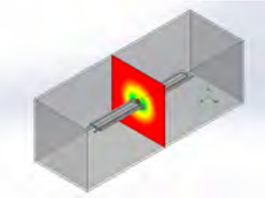
- optimise mesh settings
  - → too coarse: results unreliable
  - → too fine: computing time and resources skyrocket!

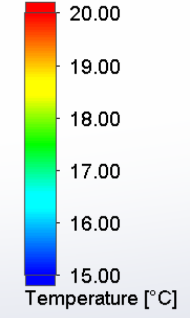




Power consumption: ~ 2.1 W





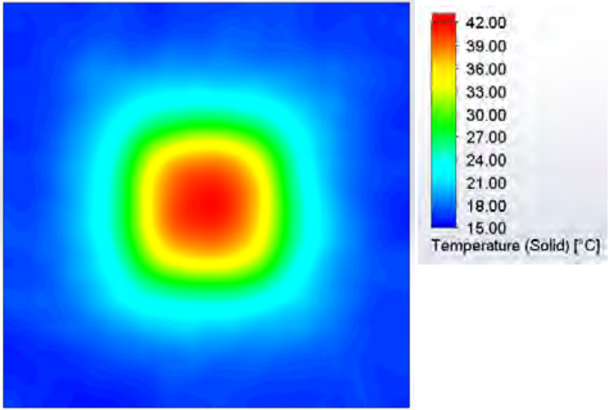


Temperature approximation

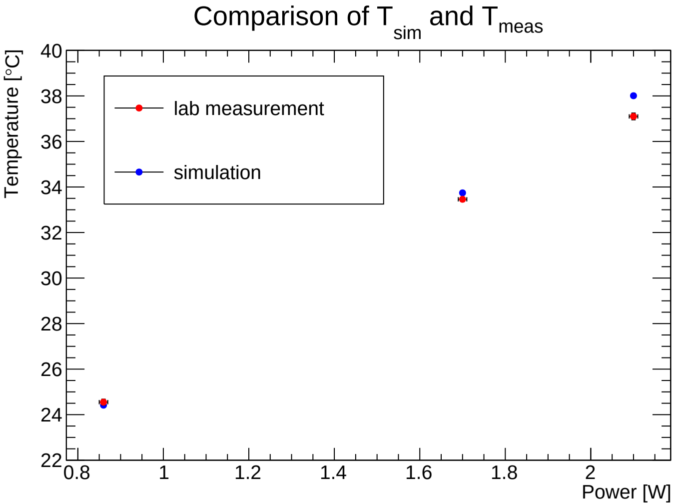
- temperature sensor: $\sim$ 4.5 x 4.5 mm^2
- **simulation**: approximate using circle with $\varnothing = 4.5$ mm
  $\rightarrow$ average over area

$\rightarrow$ for $P_{chip} \approx 2.1$ W: $T^{sim}_{top} \approx 38°C$
$T^{meas}_{top} \approx 37°C$

package top:



Comparison with lab measurements



→ very good agreement between data and simulation (difference $\leq 1°C$)

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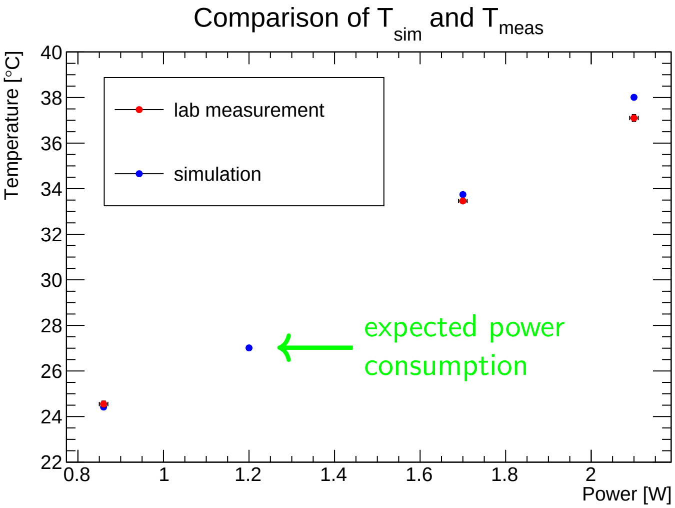

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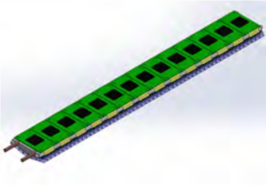
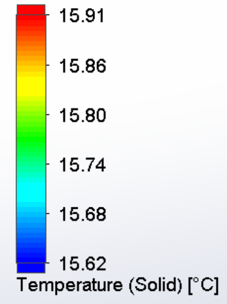
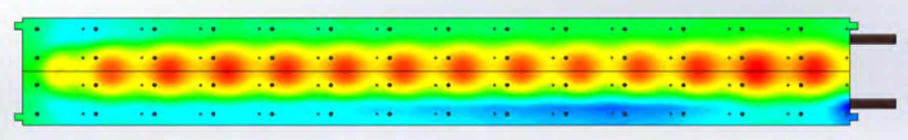
Simulation of full module

in progress





bottom view of the **cooling plate** (SiPM/tile side):



$T_{min} = 15.62°C$, $T_{max} = 15.91°C$
→ small heat gradient

water inlet

Summary and outlook

summary:

- thermal simulation is important to finalise detector design
- simulation of simple setup $\leftrightarrow$ direct comparison to lab measurements
  - $\rightarrow$ preliminary results look promising

next steps:

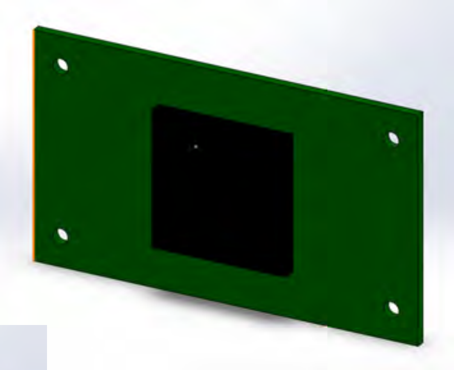
- full module simulation
- test changes in geometry
  - $\rightarrow$ thinner cooling plate, smaller pipes, ...
- module surrounded by helium (gradient!)
  - $\rightarrow$ **effect on SiPMs?**

Thank you for your attention!

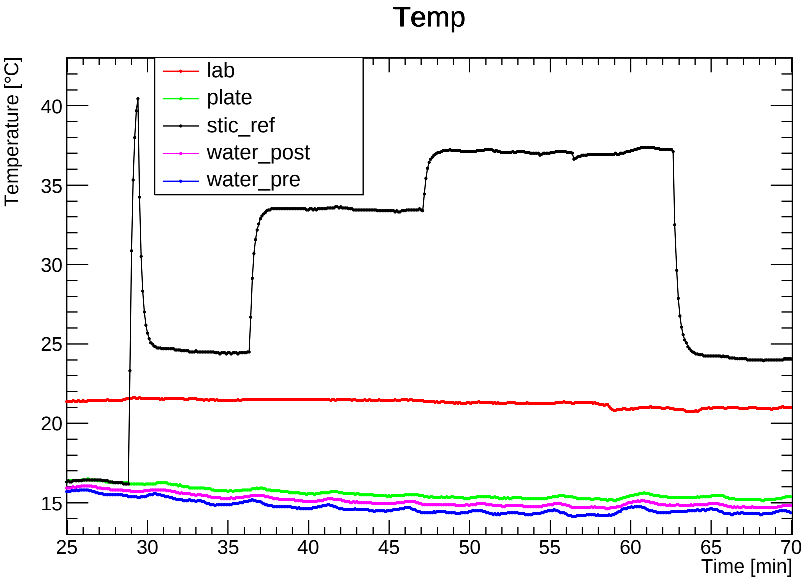
Appendix

Chip and PCB modelling

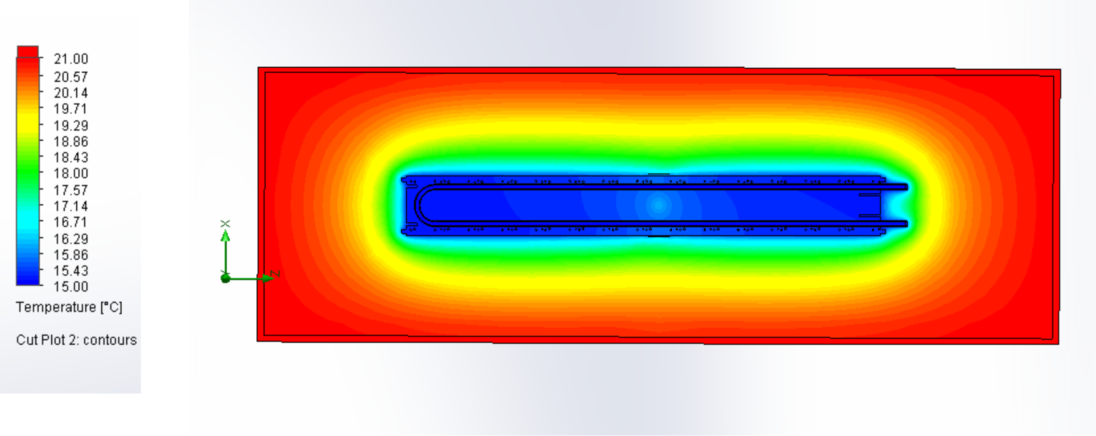
- ASIC in lab setup and simulation: **STiC V3**
  - → predecessor of MuTRiG
- chip and package modelling
  - → heat transfer defined "by hand" (based on data from manufacturer)
- PCB modelling
  - → thermal vias implemented in STiC PCB



Power consumption: ∼ 2.1 W: flow speed



Power consumption: $\sim$ 2.1 W: top view



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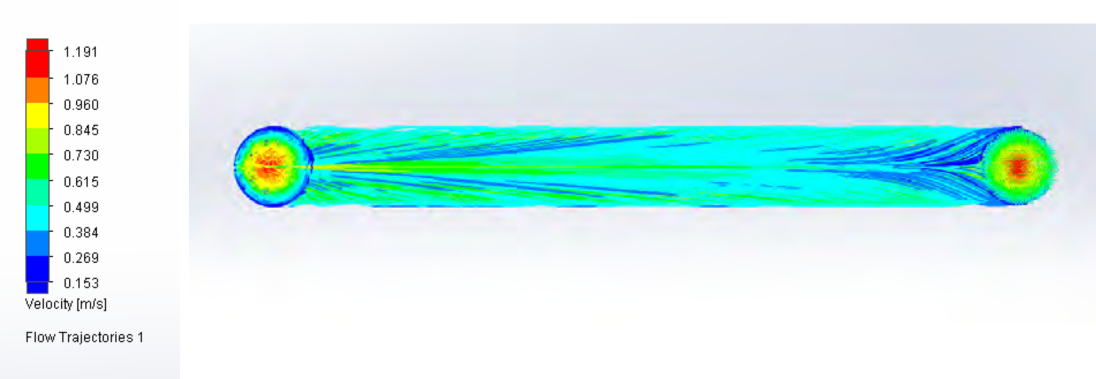
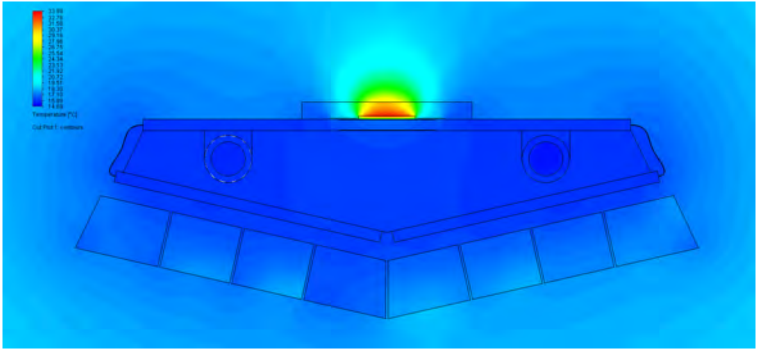


Full module




15.79
15.75
15.70
15.66
15.61
15.57
15.52
15.48
15.43
15.39
15.35
15.30
15.26
15.21
15.17
15.12
15.08
Temperature (Solid) [°C]
Surface Plot 5: contours