Simulation studies of the technical prototype for the Mu3e Tile Detector

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The decay $\mu \rightarrow eee$

- 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:**
  - via neutrino oscillation
  - suppressed by more than $O(10^{-54})$
- observation would be sign of new physics
- current limit: $\text{BR} < 10^{-12}$ 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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2) **accidental background:**

- muon decay + electron-positron scattering
- veto via precise vertex and **time** determination

[scheme by Frank Meier Aeschbacher]
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\begin{itemize}
  \item muon decay + electron-positron scattering
  \item veto via precise vertex and \textbf{time} determination
\end{itemize}

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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

$\vec{B} = 1$ T

$\sim 20$ cm

$\sim 120$ cm
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)
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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- reduction of accidental background by factor 100
Thermal simulation - motivation

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

1) Tile Detector surrounded by pixel detector
   → cooled with helium ⇒ heat gradient
   → SiPM operation? (⇒ HV?)

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

→ **full detector simulation important to finalise design!**
idea:

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

→ goal: reliable simulation
  - 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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- input from lab measurements:
  → water temperature: 15°C
  → volume flow of water: 4.7 cm³/s
  → environment temperature: 21°C
  → different chip power consumptions:
    → ~ 2.1 W
    → ~ 1.7 W
    → ~ 0.86 W
  ⇒ measurement of chip temperature
Meshing

- optimise mesh settings
  - too coarse: results unreliable
  - too fine: computing time and resources skyrocket!
Power consumption: $\sim 2.1$ W
Temperature approximation

- temperature sensor: $\sim 4.5 \times 4.5 \text{ mm}^2$

- **simulation**: approximate using circle with $\varnothing = 4.5 \text{ mm}$
  - → average over area

  for $P_{\text{chip}} \approx 2.1 \text{ W}$: $T_{\text{top}}^{\text{sim}} \approx 38^\circ\text{C}$
  $T_{\text{top}}^{\text{meas}} \approx 37^\circ\text{C}$
Comparison with lab measurements

→ very good agreement between data and simulation (difference ≤ 1°C)
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\[ \text{very good agreement between data and simulation (difference } \leq 1^\circ\text{C)} \]
Simulation of full module

in progress

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

\[ T_{\text{min}} = 15.62^\circ C, \quad T_{\text{max}} = 15.91^\circ C \]

→ small heat gradient

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Temperature (Solid) [\(^\circ C\)]

water inlet
Summary and outlook

**summary:**

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

**next steps:**

- full module simulation
- test changes in geometry
  - thinner cooling plate, smaller pipes, ...
- module surrounded by helium (gradient!)
  - 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: $\sim 2.1$ W: flow speed

![Graph showing temperature variations over time](image-url)
Power consumption: $\sim 2.1 \text{ W}$: top view
Power consumption: $\sim 2.1 \text{ W}$: flow speed
Full module