Toward Construction of the Mu3e Detector

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The Mu3e Experiment

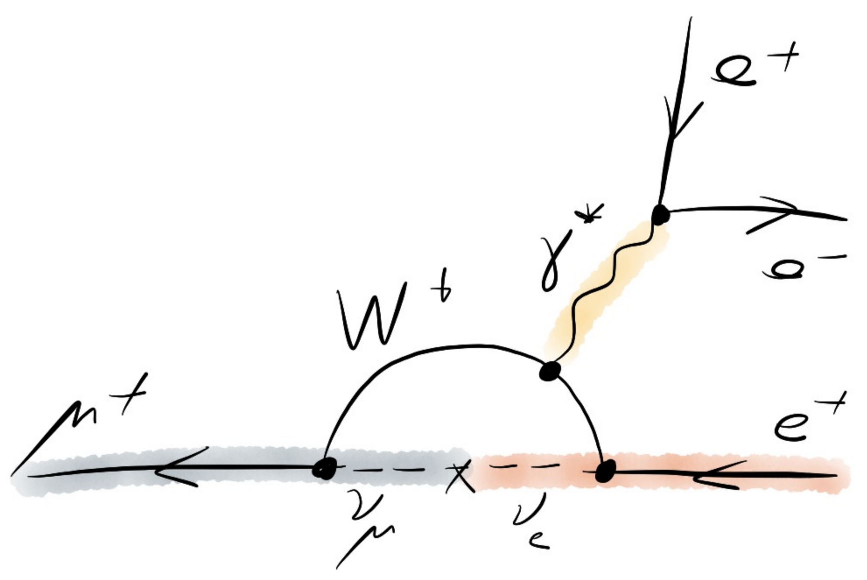


Figure 1: Standard Model decay channel of $\mu^+ \rightarrow e^+ e^- e^+$

The Mu3e experiment is searching for the lepton flavor violating decay $\boldsymbol{\mu^+ \rightarrow e^+ e^- e^+}$ with a sensitivity of 1 event in 10^{16} decays in phase II. In the Standard Model (SM), this process is highly suppressed with a branching ratio below 10^{-54}. Thus, an observed signal would indicate the presence of new physics. [1]

The Decay $\mu^+ \rightarrow e^+e^-e^+$

Muons are stopped on a target where they decay at rest. The decay $\mu^+ \rightarrow e^+ e^- e^+$ has the following signature (Fig. 2) and characteristics:

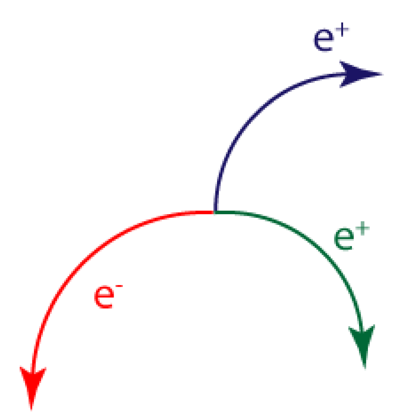


Figure 2: Decay signature

- Common vertex
- Coincident in time
- Vanishing total momentum ($\Sigma\, p = 0$)
- Maximal electron momentum of $p_e \leq 53\,\mathrm{MeV}/c$
- Total energy equals muons mass ($E_{tot} = m_\mu c^2$)

Challenges

Time resolution

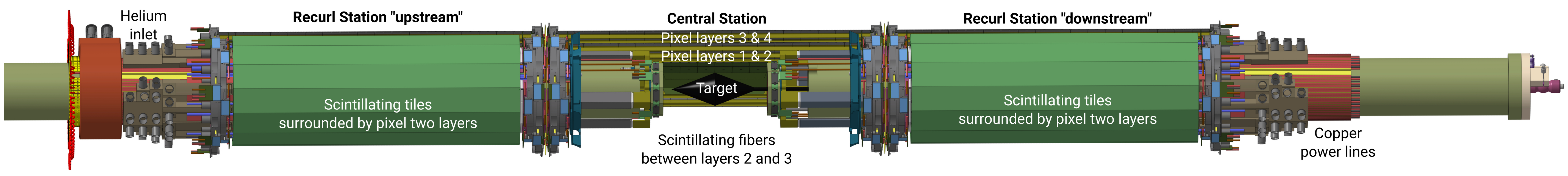
- Good timing is necessary to distinguish accidental background from signal
- Scintillating fiber and tile detectors with time resolution of $\sigma_{tile(fiber)} < 100(500)$ ps

Momentum resolution

- Irreducible background from $\mu^+ \rightarrow e^+ e^- e^+ \nu \bar{\nu}$ is kinematically suppressed for low momentum transfer to neutrinos
- Multiple Coulomb scattering dominates tracking resolution
- Thin monolithic pixel sensors needed
- Ultra-thin support structure containing cooling, powering, and readout

The Detector System [2]

- High-voltage monolithic active pixel sensors (HV-MAPS) used for tracking detector
- Four central, and two outer pixel layers
- Sensors are mounted on ultra-thin polyimide-aluminum high-density interconnects as only support structure (Fig. 3)
- Radiation length of $0.115\,\%$ per layer



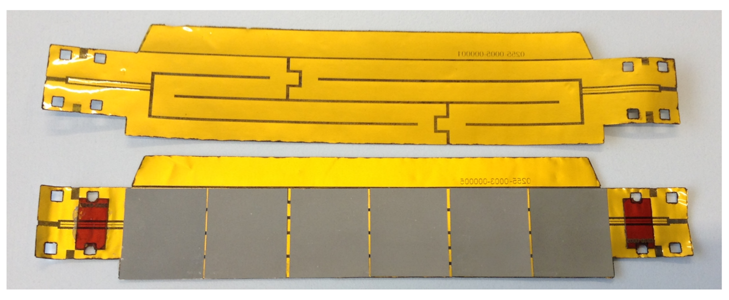


Figure 3: Sensor dummies on polyimide ladder

Polyimide Aging Studies

Why study aging of polyimide

- Polyimide is only support structure of pixel ladders
- It is deemed to be radiation hard
- But: Indications for radiation damage in inert atmosphere like helium or vacuum

Irradiation campaign in Heidelberg

- Desiccator setup (Fig. 4) to enclose polyimide samples for several weeks/months in inert atmosphere
- Irradiation with ^{90}Sr source of $\sim 70\,\mathrm{MBq}$
- Chemical analysis using solid-state NMR (TU Darmstadt)

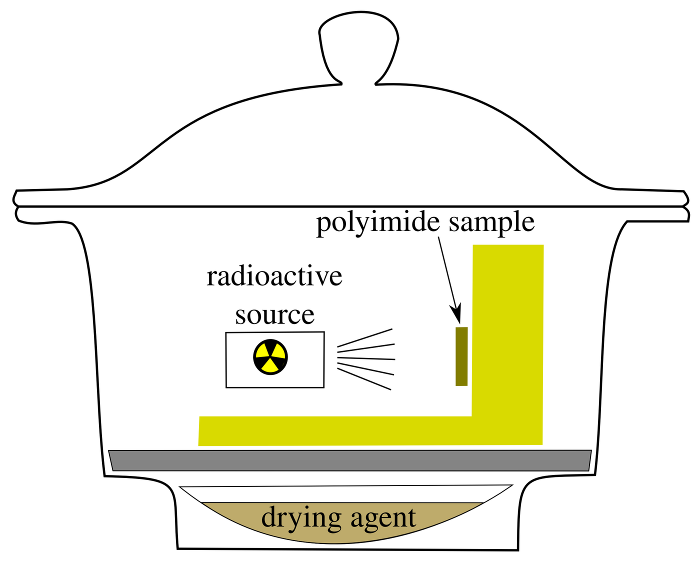


Figure 4: Desiccator setup for polyimide irradiation

The Cooling Concept

Pixel sensors are cooled by gaseous helium only. The maximum temperature allowed is $70\,°\mathrm{C}$. The cooling was tested using a detailed mockup for the inner tracking layers 1 & 2:

- Construction of thermal-mechanical mockup (uniformly heatable)
- Operation at maximum allowed heat dissipation of $400\,\mathrm{mW/cm^2}$. Helium with a flux of $10\,\mathrm{m/s}$ in gap between layer 1 & 2
- Compare resulting temperatures to simulations

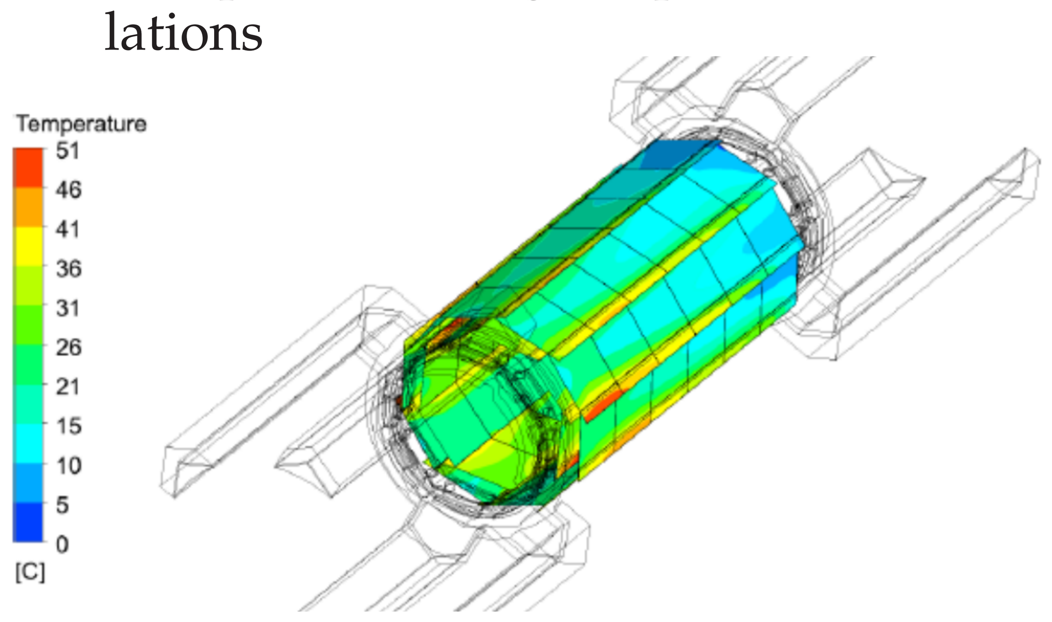


Figure 5: Simulated sensor temperature (maximum heat dissipation, additional flow around layer 2)

Results were [3]:

- Maximum reached temperature of $80\,°\mathrm{C}$
- Simulations show maximum temperature in sensor periphery of even $90\,°\mathrm{C}$

Proposal for improvement:

- Introduction of a flow around layer 2
- Simulation show reduction of maximum temperature to $51\,°\mathrm{C}$ (Fig. 5)

Powering the Pixel Sensors

System requirements:

- Sensors supply voltage of $1.9 - 2.1\,\mathrm{V}$
- Power provided by DC-DC converters with an intrinsic output ripple ($\sim 15\,\mathrm{mV}$ peak to peak; Fig. 6)
- Distance to power supplies up to $1\,\mathrm{m}$
- No space for electrical filter components next to sensor

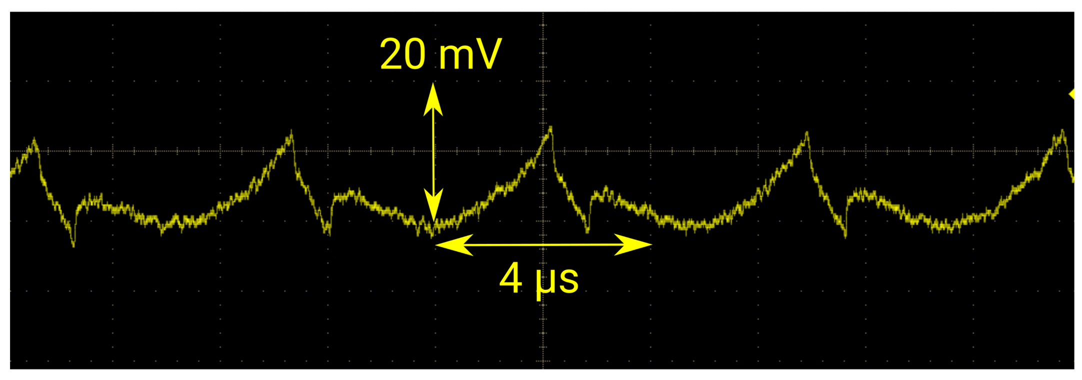


Figure 6: Output ripple of the DC-DC converter

Power is guided via copper bus bars glued on beam pipe. A first prototype (Fig. 7) is used to study:

- Bode plot of power lines
- To be measured: How much ripple can be tolerated at sensor input?

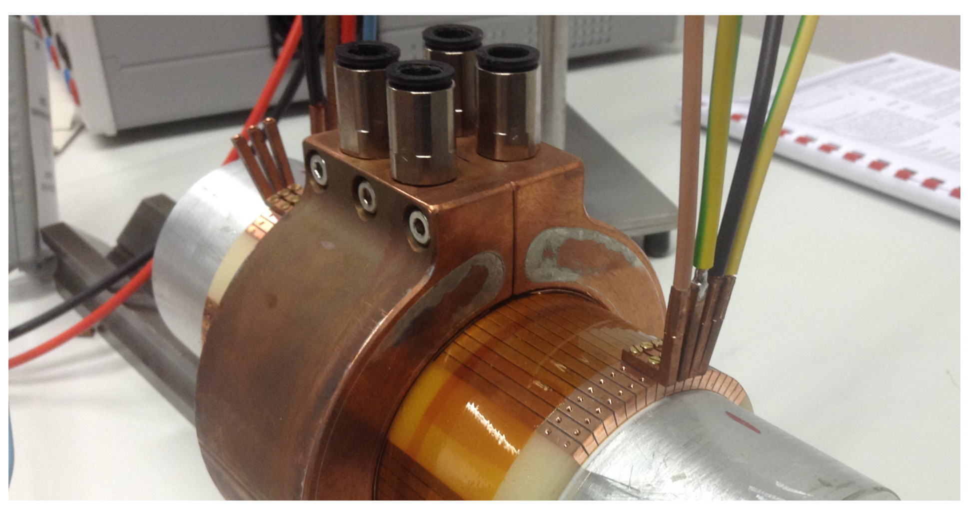


Figure 7: Shortened power line prototype

References

[1] A. Blondel et al. *Research Proposal for an Experiment to Search for the Decay $\mu \rightarrow eee$* arXiv: 1301.6113 (2013)

[2] Mu3e collaboration. *Mu3e Technical Design Report*, Internal document (2019)

[3] M. Deflorin. *Helium cooling of Silicon Pixel Detector for Mu3e Experiment*, Master thesis at FHNW