PROCEEDINGS OF SCIENCE

The Power Distribution System for the Mu3e Experiment

PoS(NuFact2021)225

Sophie Gagneur[a,*] **and Lucas S. Binn for the Mu3e collaboration**[a]

[a] *Institut für Kernphysik, Prisma*$^+$ *Cluster of Excellence, JGU Mainz*
Johann-Joachim-Becher-Weg 45, Mainz, Germany

E-mail: sogagneu@uni-mainz.de, lbinn@students.uni-mainz.de

The Mu3e experiment under construction at the Paul Scherrer Institute, Switzerland, aims to search for the lepton flavour violating decay of a muon into one electron and two positrons with an ultimate sensitivity of one in 10^{16} muon decays. The detector for the Mu3e experiment consists of High-Voltage Monolithic Active Pixel Sensors (HV-MAPS) combined with scintillating tiles and fibres for precise timing measurements. The entire detector and front-end electronics are located in the 1m diameter bore of a 1T superconducting magnet. A compact power distribution system based on custom DC-DC converters provides the detector ASICs and readout FPGAs with supply voltages of 1.1V to 3.6V with currents up to 30A per channel. These converters are placed as close as possible to the detector and provide 10kW of power in total. For the whole experiment a total of 126 DC-DC converters is required. The paper presents the results of recent prototype tests and the path to the production of the full power system.

**** The 22nd International Workshop on Neutrinos from Accelerators (NuFact2021) ****
**** 6–11 Sep 2021 ****
**** Cagliari, Italy ****

*Speaker

1. The Mu3e Experiment

The aim of the Mu3e experiment is to contribute to the search for new physics. The focus is set on the decay of a positive muon into one electron and two positrons $\mu^+ \rightarrow e^+e^+e^-$ which would be clear evidence of charged lepton flavour violation. The best limit on this decay channel was set by the SINDRUM experiment at a branching fraction of 10^{-12} [2]. The Mu3e experiment aims to improve the sensitivity by 4 orders of magnitude to 10^{-16}. Optimal conditions for this project can be found at the Paul Scherrer Institute in Villigen, Switzerland with a beam intensity of 10^8 muons per second for phase I of the experiment [1]. The sensitivity of the Mu3e experiment is strongly dependent on the ability to reduce background. This can be achieved optimized detector systems with a high momentum, vertex and time resolution.

1.1 The Mu3e Detector

A schematic representation of the Mu3e detector can be seen in figure 1. The incoming muons are stopped in a thin target in the middle of the experiment and the 1T strong magnetic field deflects the trajectories of the decay positrons and electrons. The Mu3e detector can be divided into three different detector subsystems. One part is the Mu3e pixel tracker consisting of High Voltage Monolithic Active Pixel Sensors (HV-MAPS) [3]. In the context of the Mu3e experiment they are called MuPix sensors [4]. The 50µm thin sensors enable accurate track and vertex reconstruction. The optimal time resolution is provided by scintillating fibres and tiles which is for example important for the suppression of accidental background. On both ends of the detector the frontend boards (FEBs) with the readout electronics are placed.

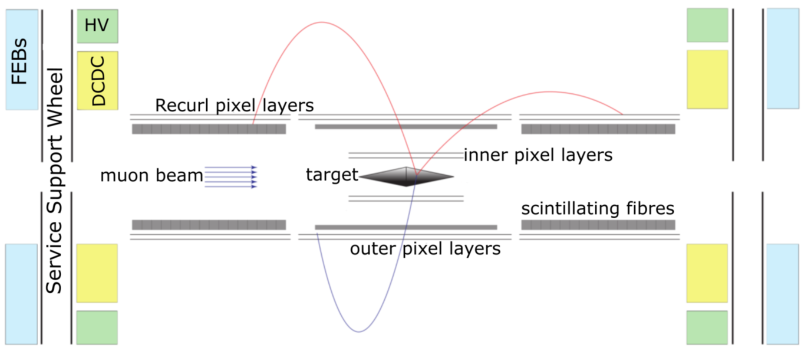


Figure 1: Schematic drawing of the Mu3e detector with pixel sensors, scintillating fibres and tiles and the service support wheels with the frontend crates containing the frontend boards (FEBs).

1.2 Power Requirements

The detector subsystems require relatively low voltages and the cables to all the detector components are very long. This would lead to high power losses through these cables. The solution chosen by the Mu3e experiment involves the use of DC-DC converters to step down a higher input voltage (20V) to the required values which are between 2.2 and 3.6 volts (see table 1).The FEBs have different power requirements which will be explained in the next section.

Detector	# partitions	V_{out}	typical current [A]	
Pixel				
layer 1 + 2	8	2.3-2.4	10.3	
layer 3 + 4	78	2.4-2.5	21.9	
Fibre	12	2.2+	7	
Tile	14	2.2+	9	
		14	3.6+	3.1

Table 1: Number of power partitions for the different detector components.

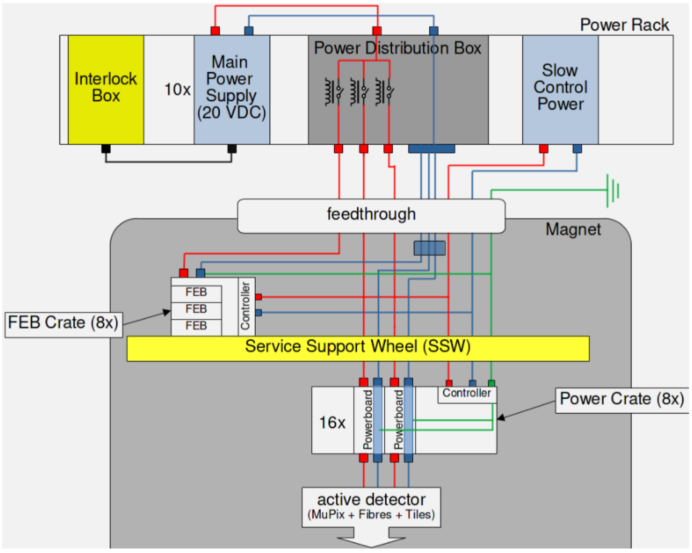
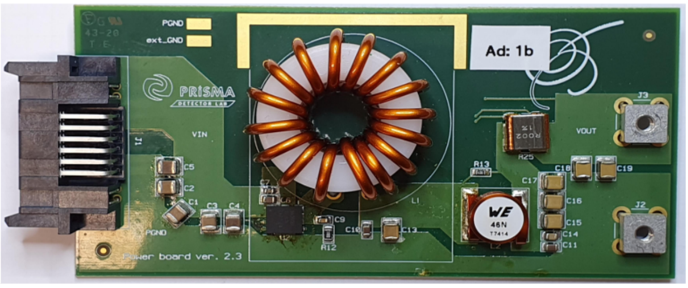


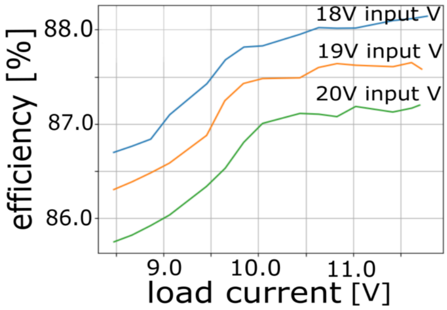
Figure 2: The power distribution system of the Mu3e experiment.

2. Power Distribution System

The Mu3e power distribution system is segmented into different power partitions (see figure 2). Each partition consists of a power supply channel, robust copper cables, one DC-DC converter and a detector component. In total the experiment needs 112 power partitions for the active detectors, namely Pixels, Fibres and Tiles, and 8 power partitions for the FEB. In a rack outside of the detector the power distribution box is located, where several power supply outputs are multiplexed via a relay bank to switch every single power partition on and off separately. The rack also multiplexes the power for the slow control which is intended for e.g. environmental sensors. Eight of the power lines are going to the FEBs located inside the magnet. On each FEB there are three buck converters embedded which are stepping down the 20V input power to 1.1V, 2.5V and 3.3V. The rest of the power partitions supply the Mu3e DC-DC converters. They are also located inside the magnet on the so called service support wheels.



(a) The second version of the Mu3e DC-DC converter.



(b) Efficiency of the Mu3e DC-DC converter

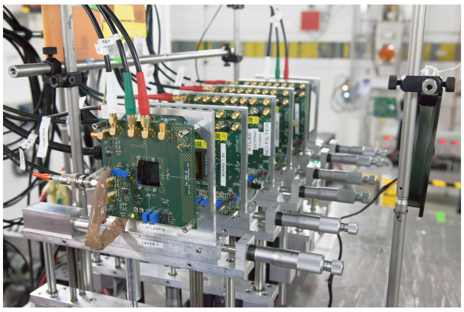
Figure 3: Technical data of the Mu3e DC-DC converter.

3. Mu3e DC-DC Converters

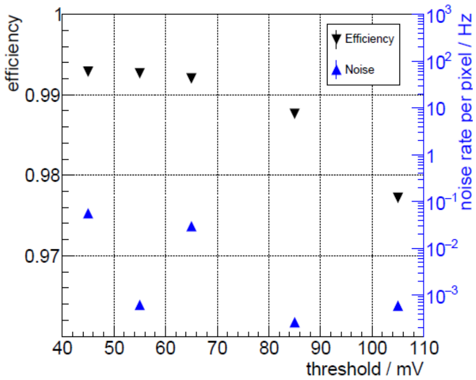
The Mu3e experiment uses custom made DC-DC converters that match the requirements of the experiment and the detectors. The converter (see figure 3a) is stepping down an input voltage of 20V to 2.1V at a switching frequency of 1MHz and employs a custom air coil with an inductivity of 0.55µH. Already the first version of the converter shows a very good efficiency of 87% at 10A load current (see figure 3b). With an output filter we could reduce the low voltage ripple of the output signal of the converter to 15mV peak to peak. The high frequency noise is still quite high and will be improved in the next version with for example an optimized PCB layout.
A second version of the Mu3e DC-DC converter with a few extra features is currently being tested in the laboratory. One of these features is a current sense measurement with a shunt resistor. Another addition is a voltage drop compensation. The detector components require very precise voltage levels, which is why the voltage drops over the cables to the subsystems should be already compensated for in the feedback loop on the converter. Currently we have different versions for this system under test. The last new implementation is a safety circuit monitoring the temperature of the pixel sensors via a diode implemented on chip, automatically cutting the power to the tracker when the MuPix overheats.

3.1 Test Beam Measurements

The first version of the Mu3e DC-DC converter has already been tested as part of a test beam at DESY [6]. For this purpose, the influence of a DC-DC converter as a power supply for a MuPix8 [5] sensor was examined. The efficiency and the noise rate of the MuPix8 sensor powered by the DC-DC converter has been measured. For the measurements the sensor was placed between 3 reference layers in a MuPix telescope [7] (see figure 4a). The DC-DC converter was controlled using a Raspberry Pi and monitored by an oscilloscope and a camera next to it. A high level of efficiency could already be expected from the previous laboratory measurements. The results can be seen in figure 4. The overall efficiency of a MuPix sensor powered by a DC-DC converter is very high at a level of 99.3%. The results show that the development of the Mu3e DC DC converter is on the right track. However, further improvements are necessary as these measurements were only tests with a single MuPix sensor.



(a) The MuPix8 telescope: one scintillating tile at the front and back for timing measurements; 4 modules with MuPix8 sensors in total, the second one is powered by the DC-DC converter.



(b) Threshold scan for noise and efficiency.

Figure 4: Results of the test beam at DESY with a MuPix8 sensor powered by a DC-DC converter.

4. Conclusion and Outlook

The Mu3e DC-DC converters are the heart of the power distribution system. The second version of the converter has already been successfully tested. The results are promising, which is why a third version is currently under development, with only minor changes compared to the previous version. The goal with this version is to power the detector modules during the commission of the experiment.

References

[1] Arndt, K. et al., *Technical design of the phase I Mu3e experiment*, Nucl. Instrum. Meth. A 1014, 165679 (2021), doi:http://dx.doi.org/10.1016/j.nima.2021.165679

[2] U. Bellgardt et al., *Search for the decay* $\mu^+ \to e^+e^+e^-$, Nuclear Physics B 299, 1 (1988), doi:https://doi.org/10.1016/0550-3213(88)90462-2

[3] Ivan Peric, *A novel monolithic pixelated particle detector implemented in high-voltage CMOS technology*, Nucl. Instrum. Meth. A 582, 876 (2007), doi:https://doi.org/10.1016/j.nima.2007.07.115.

[4] A. Schöning and J. Anders and H. Augustin et al., *MuPix and ATLASPix - Architectures and Results*, 2020, url:arXiv:2002.07253

[5] H. Augustin et al., *MuPix8 — Large area monolithic HVCMOS pixel detector for the Mu3e experiment*, Nucl. Instrum. Meth. A 936, 681 (2019), doi:https://doi.org/10.1016/j.nima.2018.09.095.

[6] R. Diener et al., *The DESY II test beam facility*, Nucl. Instrum. Meth. A 922, 265 (2019), doi:https://doi.org/10.1016/j.nima.2018.11.133.

[7] Augustin, H. et al., *The MuPix Telescope: A Thin, High-Rate Tracking Telescope*, Journal of Instrumentation (2017), doi:http://dx.doi.org/10.1088/1748-0221/12/01/C01087