# ASIC and Thermal Tests of New FBCM Luminometer for HL-LHC

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## Abstract

The Fast Beam Conditions Monitor (FBCM) is a standalone luminometer being developed for HL-LHC. It will use silicon pad sensors to operate independently from CMS data acquisition services and allows for independent luminosity and beam induced backgrounds measurement. Sensor signals are read-out via ASIC, which has been developed and is now being extensively tested. Next step foresees full readout chain test with sensors and radioactive sources.

Thermal optimization is a key part of the construction of the detector, contributing to the longevity and reliability of the system. Thermal studies have been done using inner tracker portcard prototype. Several cooling frames, thermal interfaces with diamond doped glue, and configurations of the cooling pipe were tested and compared using ANSYS simulations and thermal sensor measurements.

## FBCM Overview

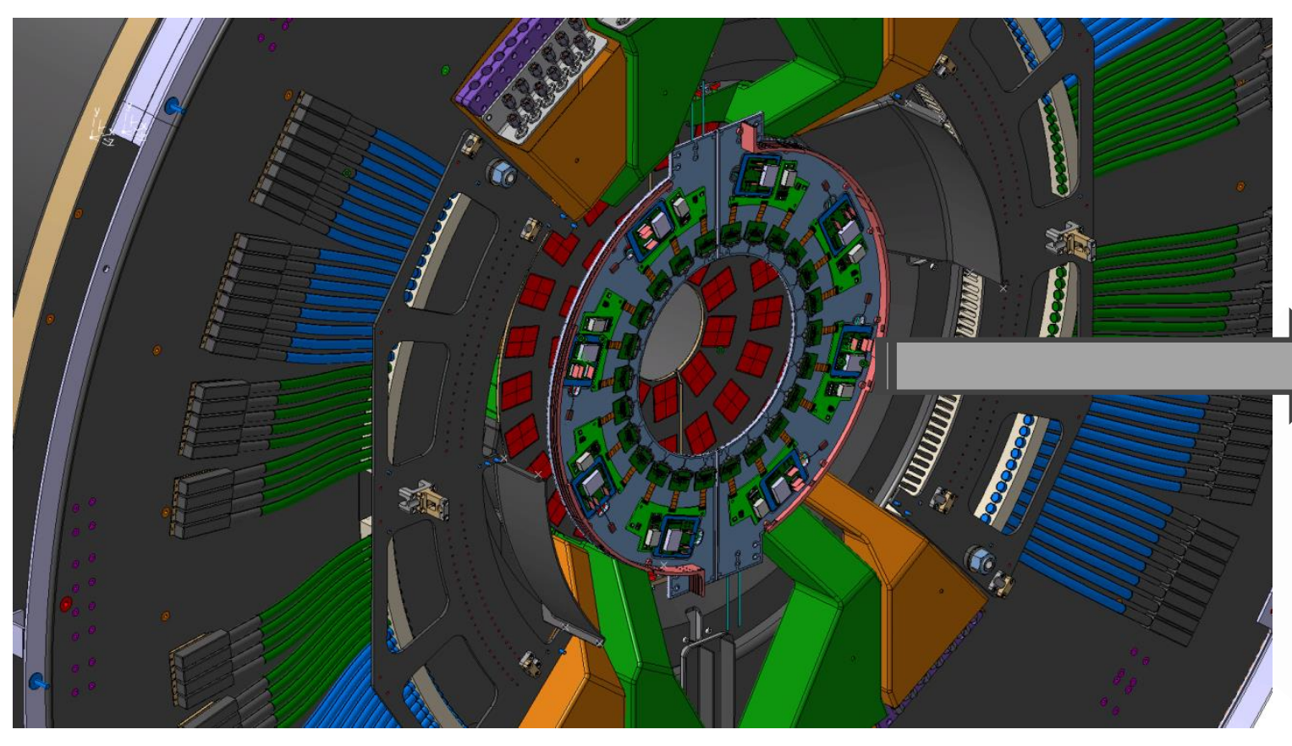


Fig. 1.1: Sketch of FBCM integration which will be located 2.8 m from the interaction point, with silicon pad sensors at radius of 14.5 cm.

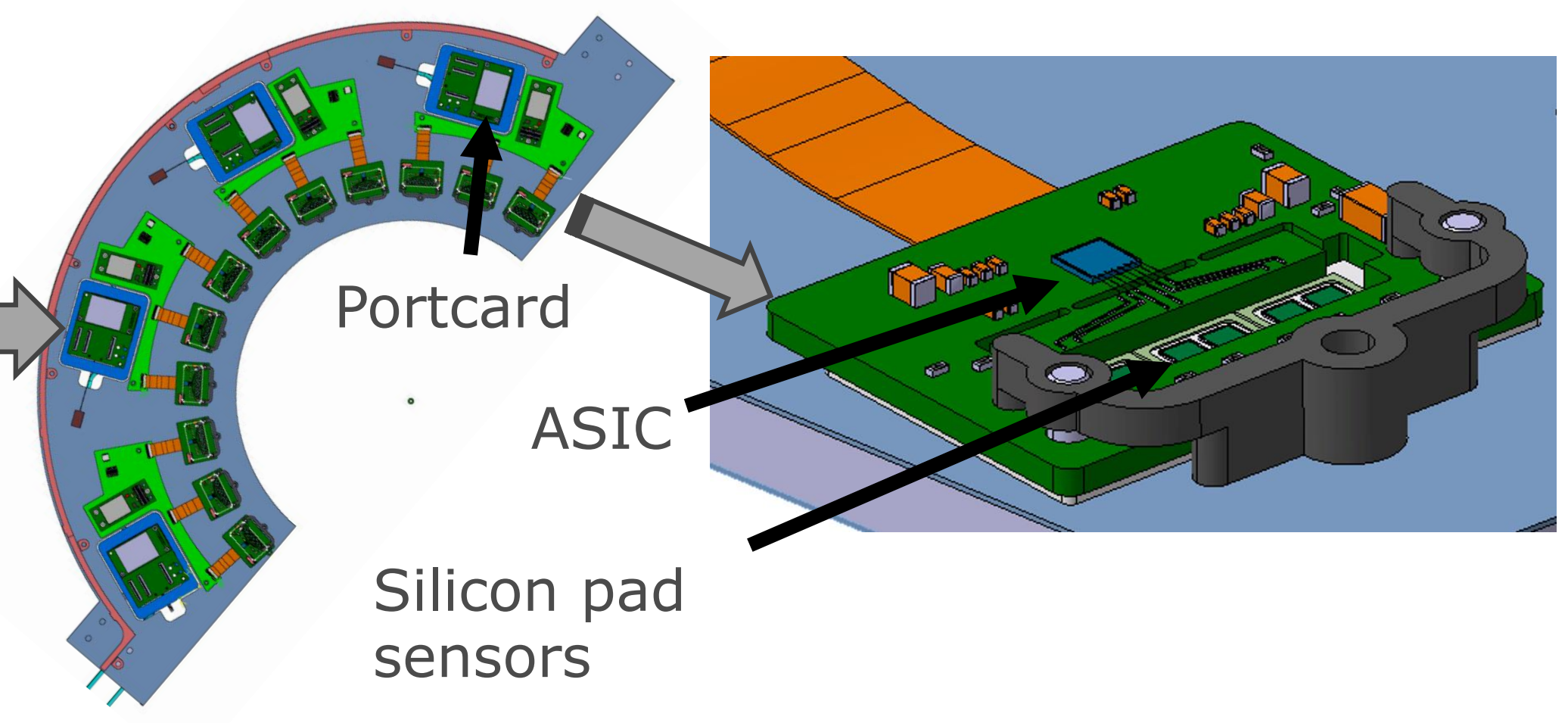


Fig. 1.2: Electrical signals from 6 sensors will be read out by new dedicated ASIC, and routed to inner tracker portcard, where VTRx+ modules mounted on lpGBTs convert electrical signals to optical signals.

The following components will be referenced to throughout the poster: lpGBT (Low-power Gigabit Transceiver), VTRx+ (Versatile Transceiver plus) and DC DC (device to convert DC voltage)[1].

## FBCM23 ASIC Testing

FBCM23 is a binary front-end ASIC designed in CMOS 65 nm. It consists of 6 channels with SLVS output, charge injection circuit and I2C interface used for programmability and calibration (see fig. 2.1). Each channel is built of charge sensitive amplifier (CSA), second amplification stage (booster), tunable RC filter (to adjust channel peaking time and track sensor degradation) and comparator with SLVS output [2].

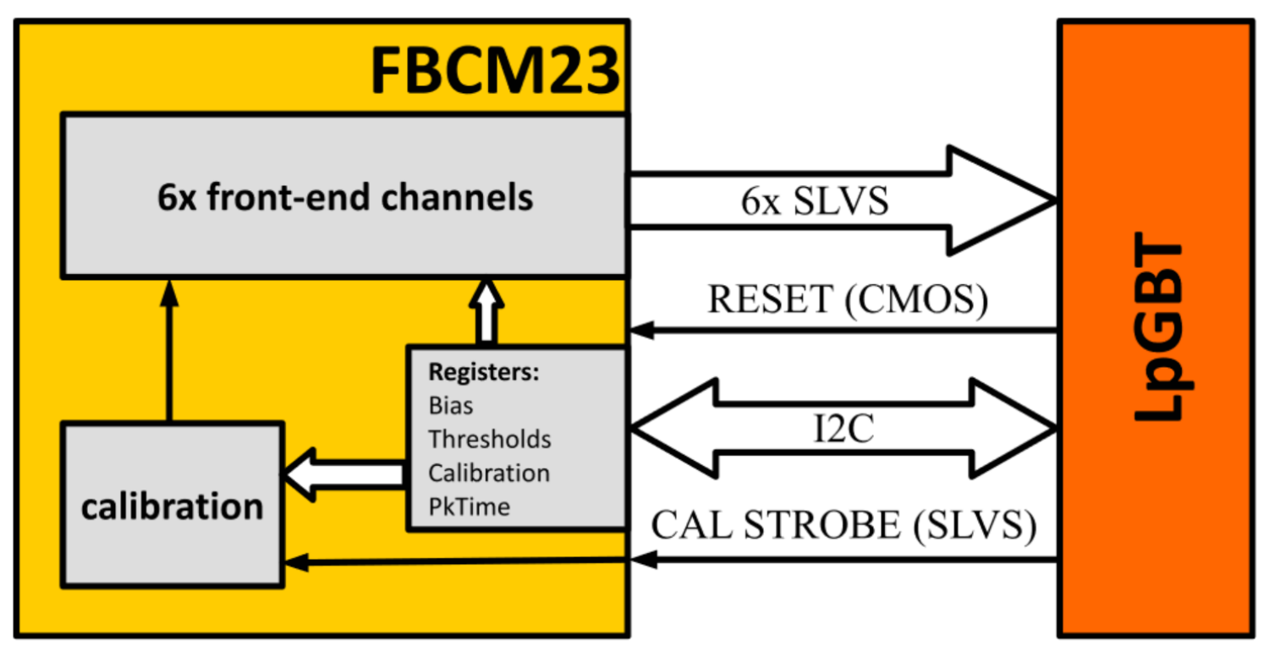


Fig. 2.1: Block diagram of the FBCM ASIC with connections to lpGBT

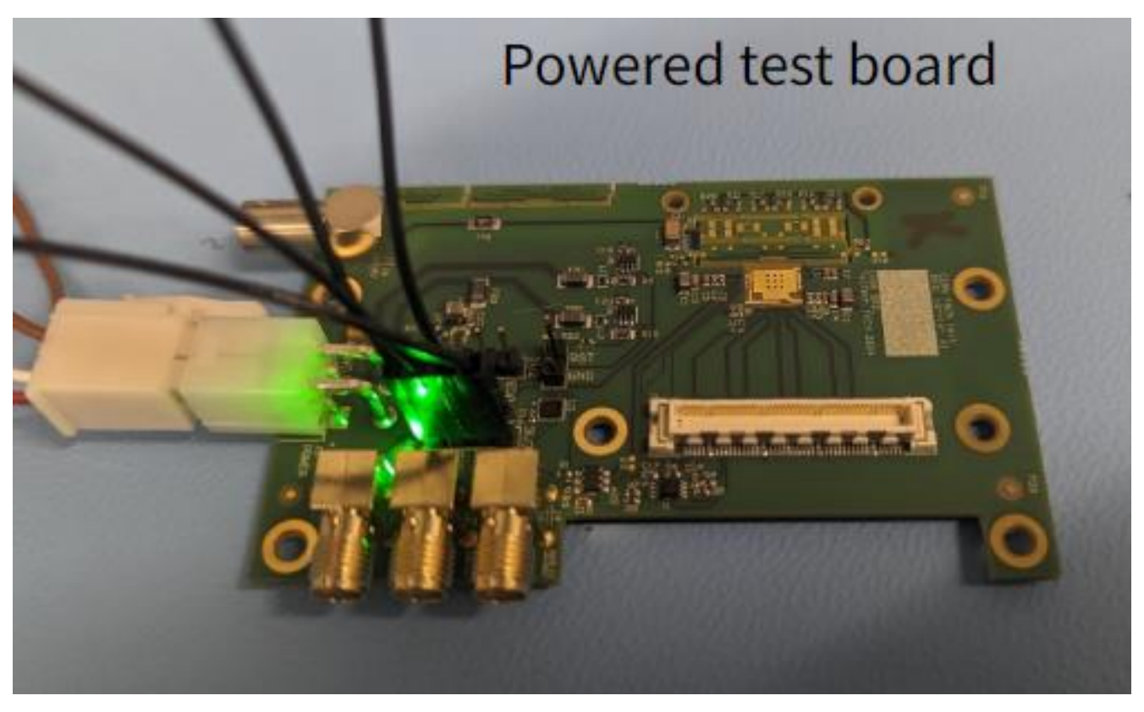


Fig. 2.2: ASIC carrier board

The ASIC tests are conducted using dedicated PCB (fig. 2.2). It provides access to all necessary chip signals, power rails decoupling, I2C level shifter and possibility to attach the detector.

Test setup (fig. 2.3 and 2.4) consists: Tektronix MSO64B scope, Agilent 81110A generator, Keysight 53220A counter, Agilent E3646A power unit and Keithley DMM7510 multimeter. I2C communication is provided by Raspberry Pi.

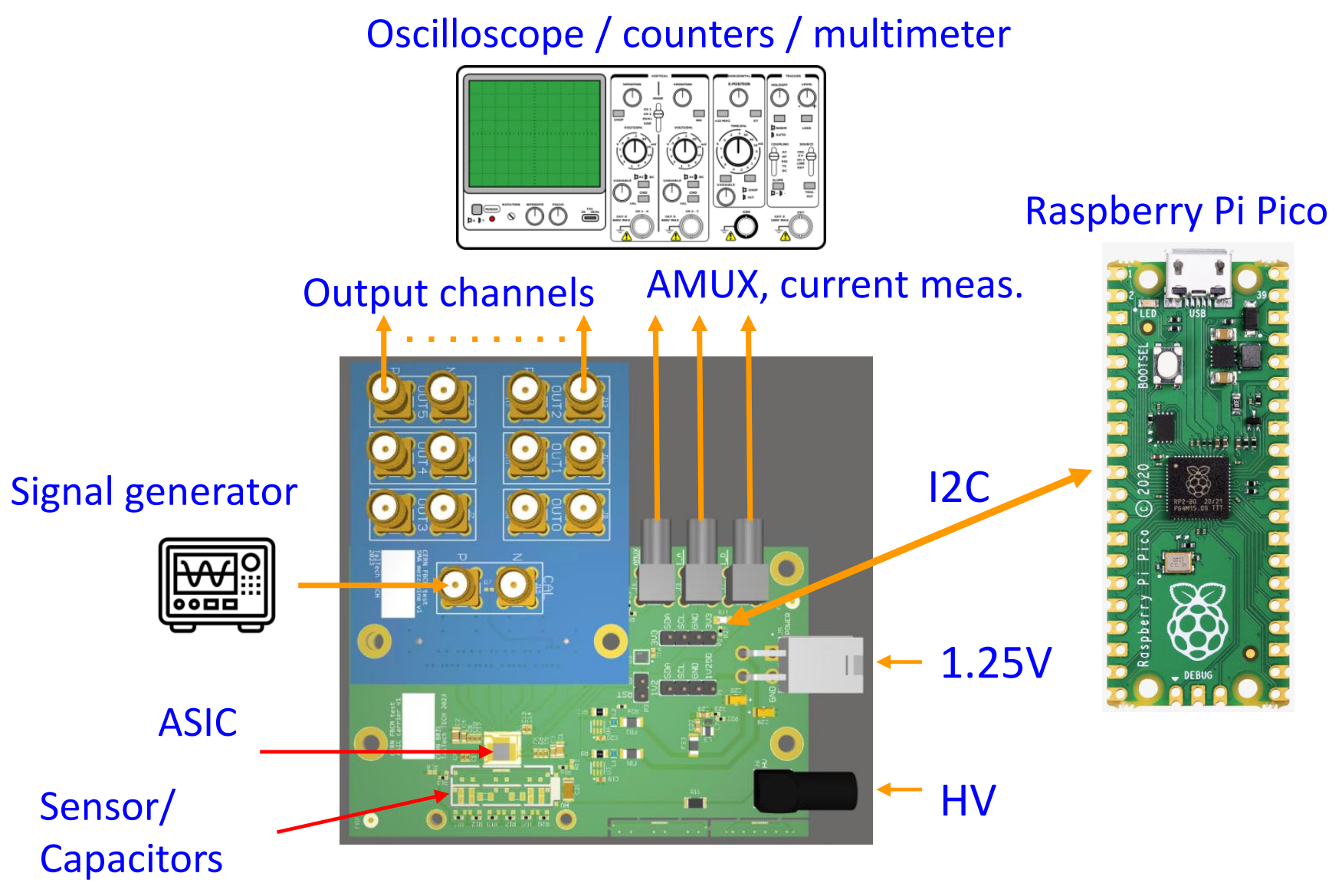


Fig. 2.3: Test setup connections

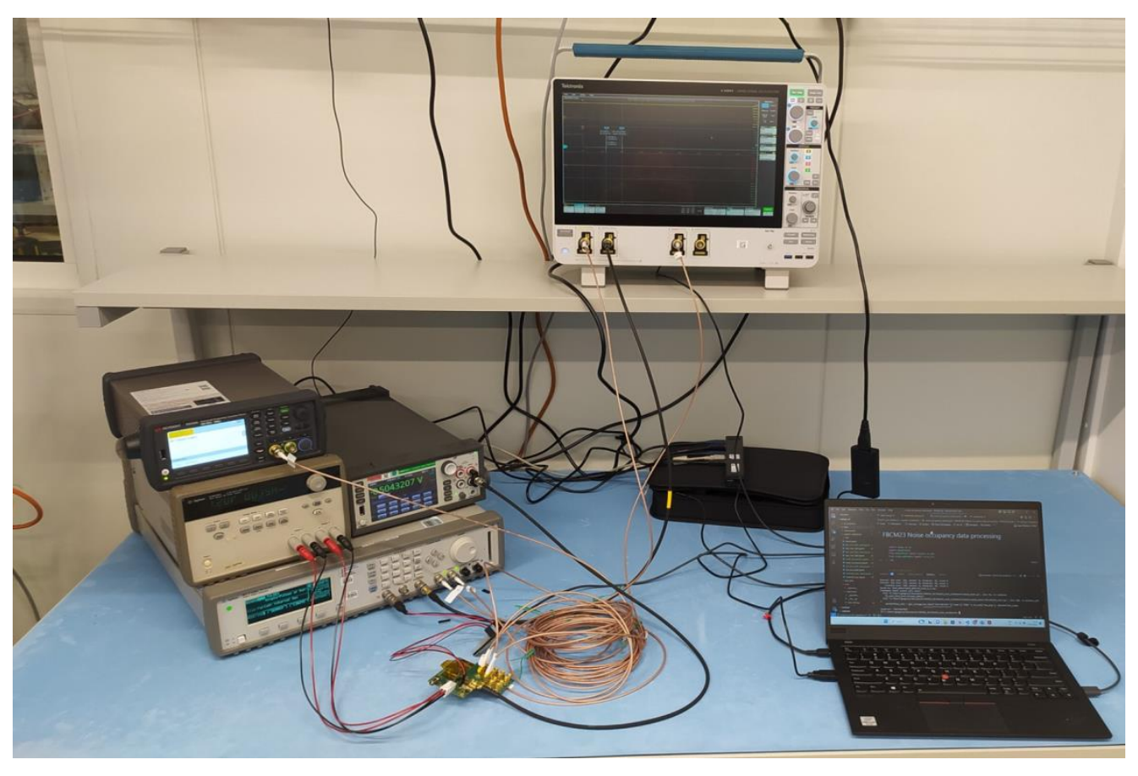


Fig. 2.4: Test setup

**Preliminary tests shows good compatibility with simulations. The gain extracted from threshold scan analysis for nominal RC is equal to 60 mV/fC (fig 2.5). Noise from noise occupancy scan is ~3mV (fig 2.6) and time walk is below 4ns (fig 2.7)**

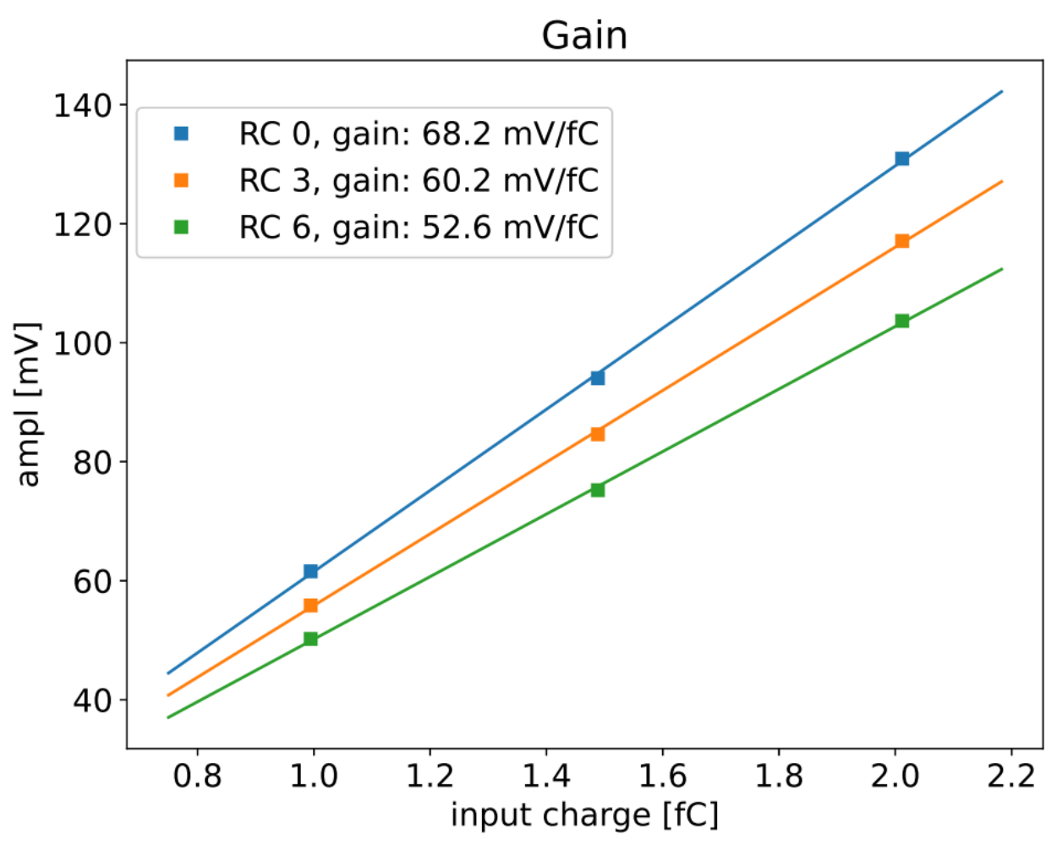


Fig 2.5: Gain measurement for RC set to 0.3 and 6.

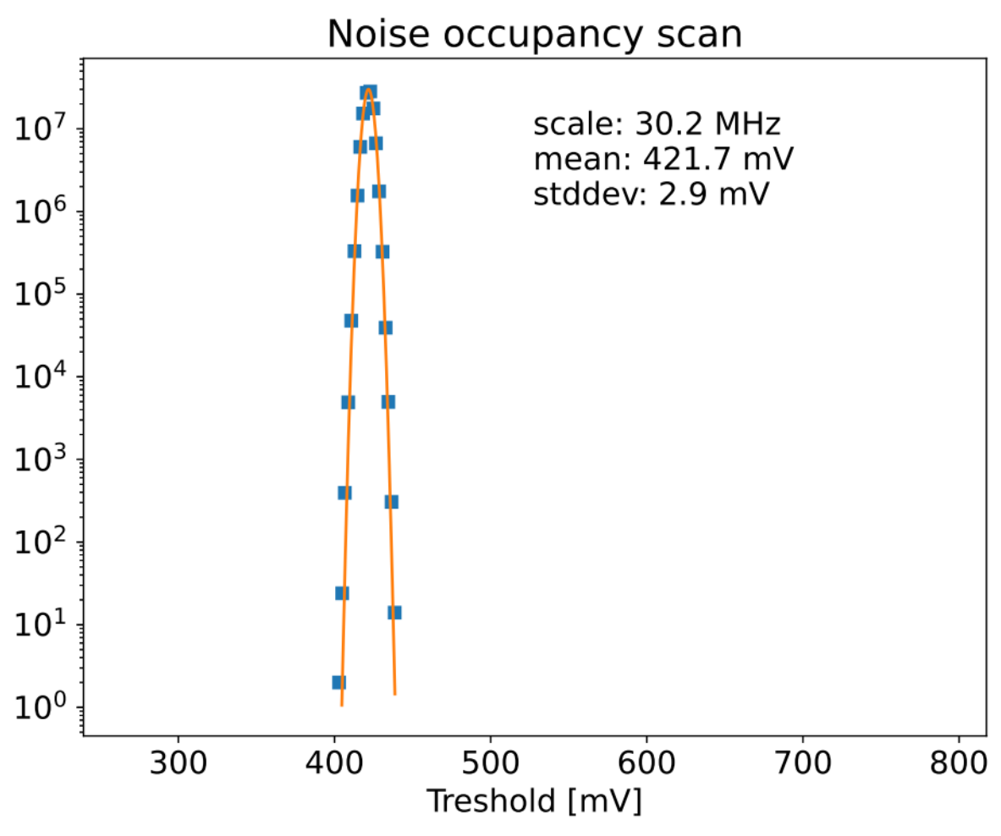


Fig. 2.6: Noise occupancy scan for the channel with unloaded input

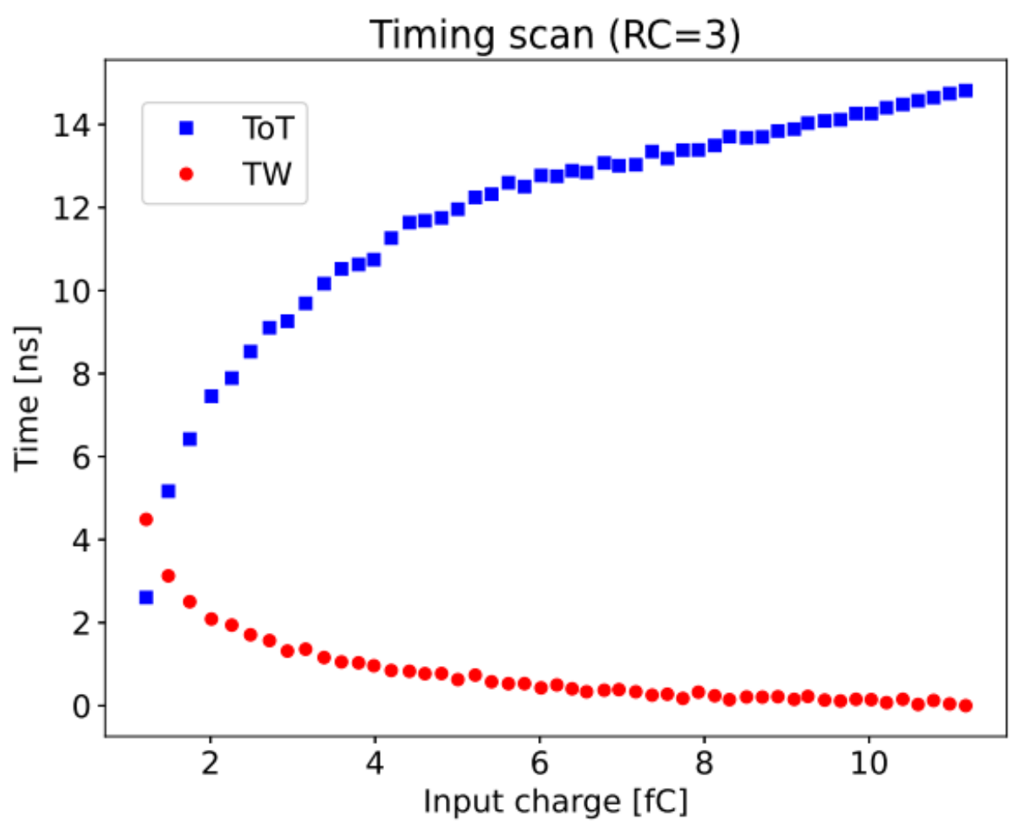
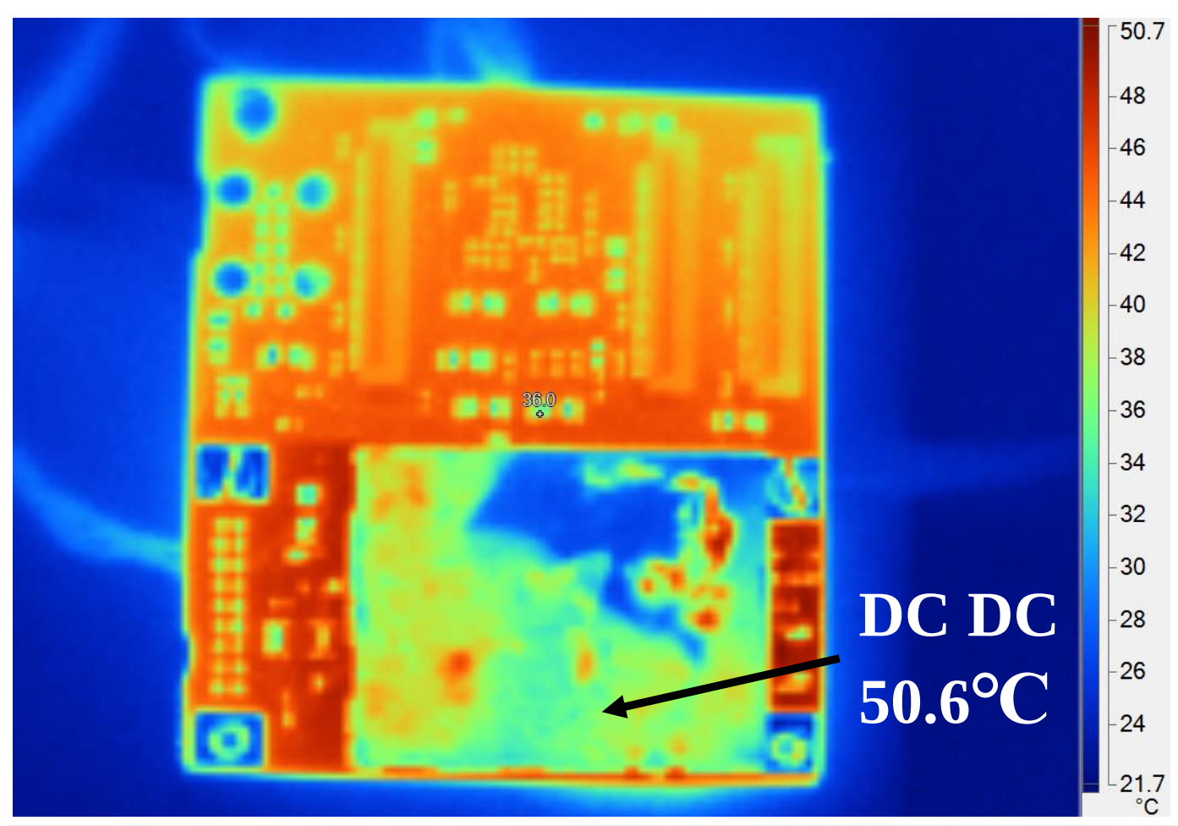


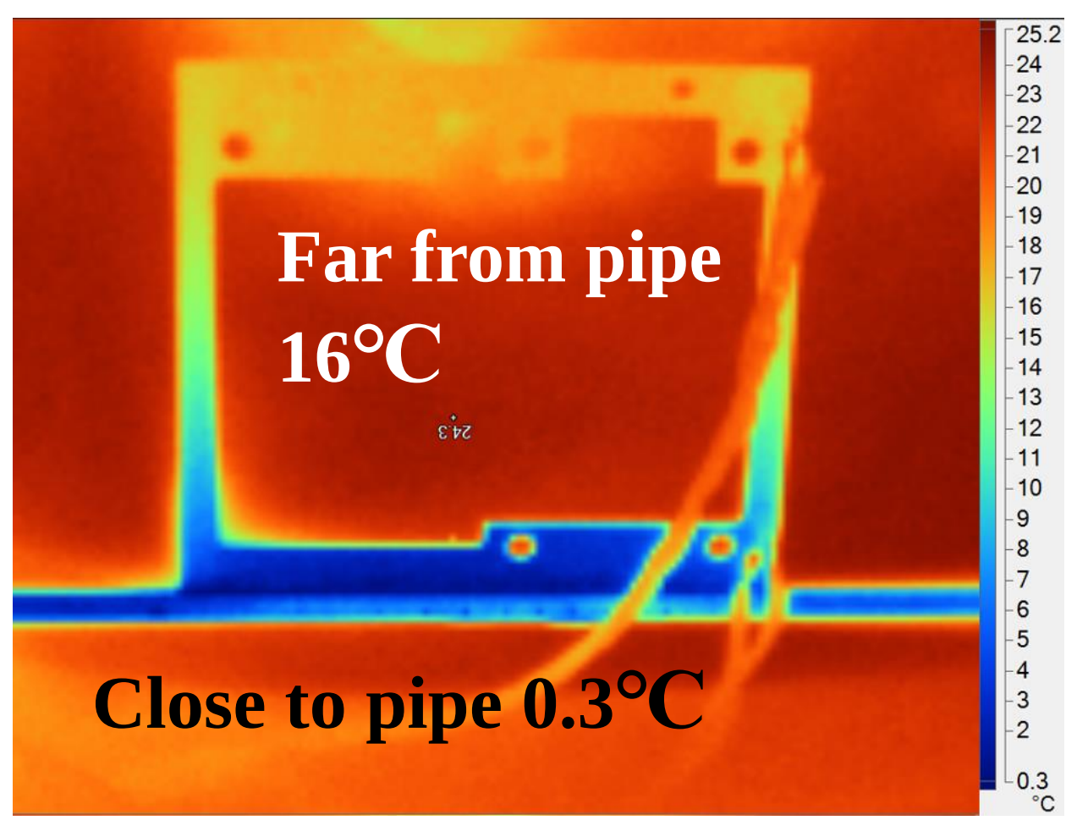
Fig. 2.7: Time walk and time over threshold (threshold set to 1 fC)

## Portcard Heat Generation & Cooling Prototypes

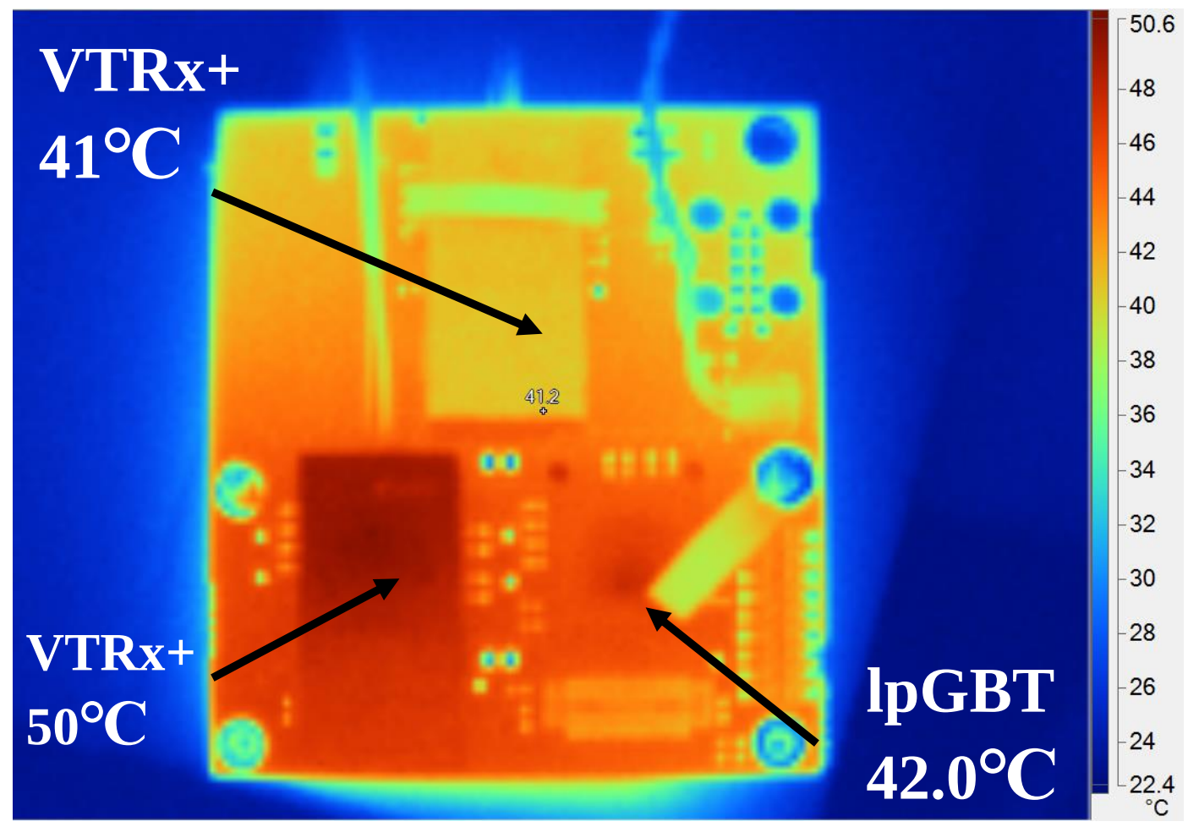
Signals from ASIC are routed to the portcard, which generates heat (Fig 3.1 & 3.3) and has increased power consumption when attaching a VTRx+ module on the lpGBT. This heat production is managed by mounting portcard on cooled frame.



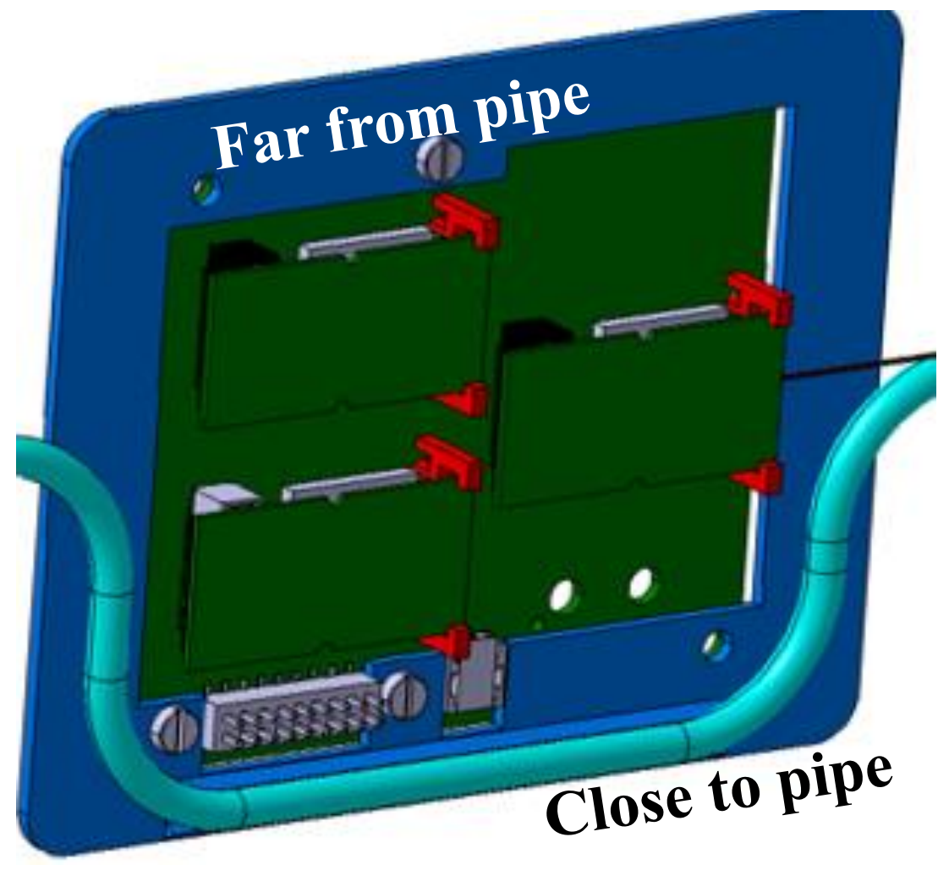
(Left) Fig. 3.1: Thermal camera image of top side of portcard. **DC DC is hottest.**



(Right) Fig. 3.2: Straight pipe cooled at -10℃ mounted on carbon frame. **Hot regions far from cooling pipe.**



(Left) Fig. 3.3: Thermal image of bottom side of portcard. **VTRx+ placed opposite DC DC is hottest.**



(Right) Fig. 3.4: **New proposed banded pipe** configuration – aims to improve cooling far from pipe.

## Portcard Steady State Thermal Simulations using ANSYS

Simulations of the portcard cooling frame were done using ANSYS Mechanical and solved remotely via RSM & HTCondor. Confirmed agreement of simulation results with thermal sensors and camera.

**Carbon fiber has directional thermal conductivity:** $\lambda_z = 2\ W/mK$, $\lambda_{xy} = 200\ W/mK$.

**Aluminum has isotropic thermal conductivity:** $\lambda = 237\ W/mK$.

**Convection in pipe: -35℃, Convection of surroundings: -10 ℃**

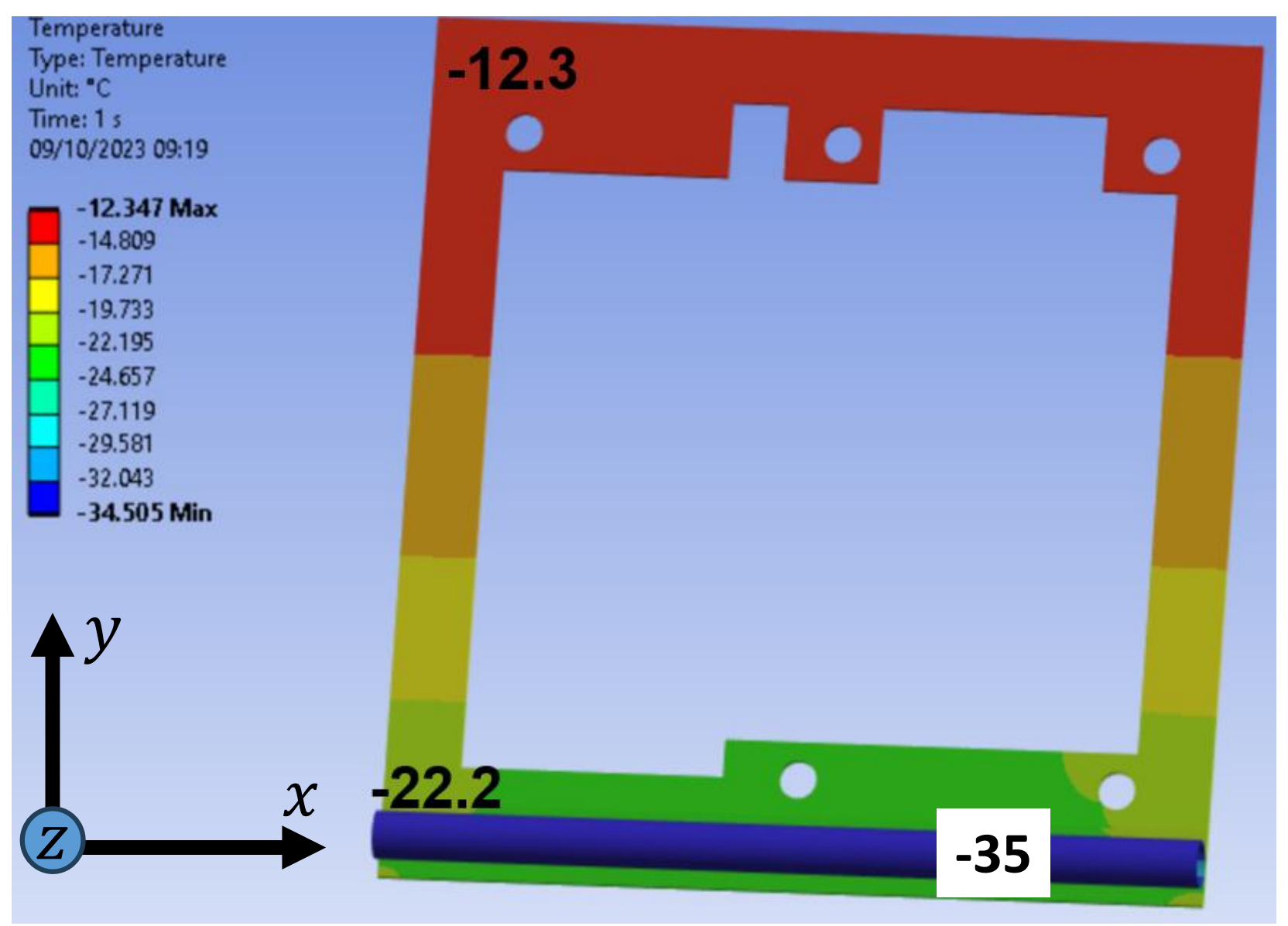


Fig. 4.1: Simulation of **0.4mm Carbon Fiber** frame with straight pipe cooling configuration.

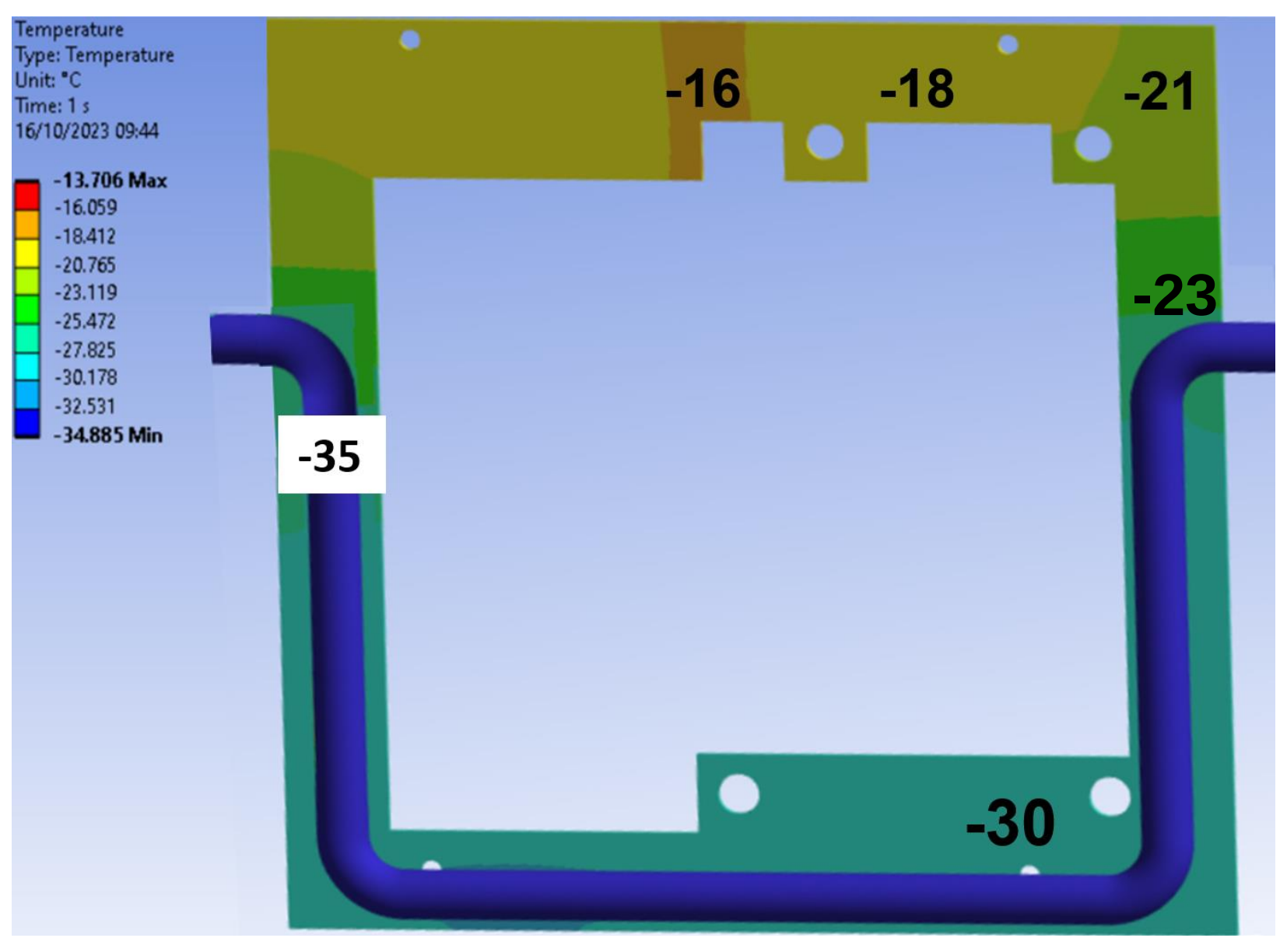


Fig. 4.2: Simulation of **0.4mm Carbon Fiber** frame with banded pipe cooling configuration.

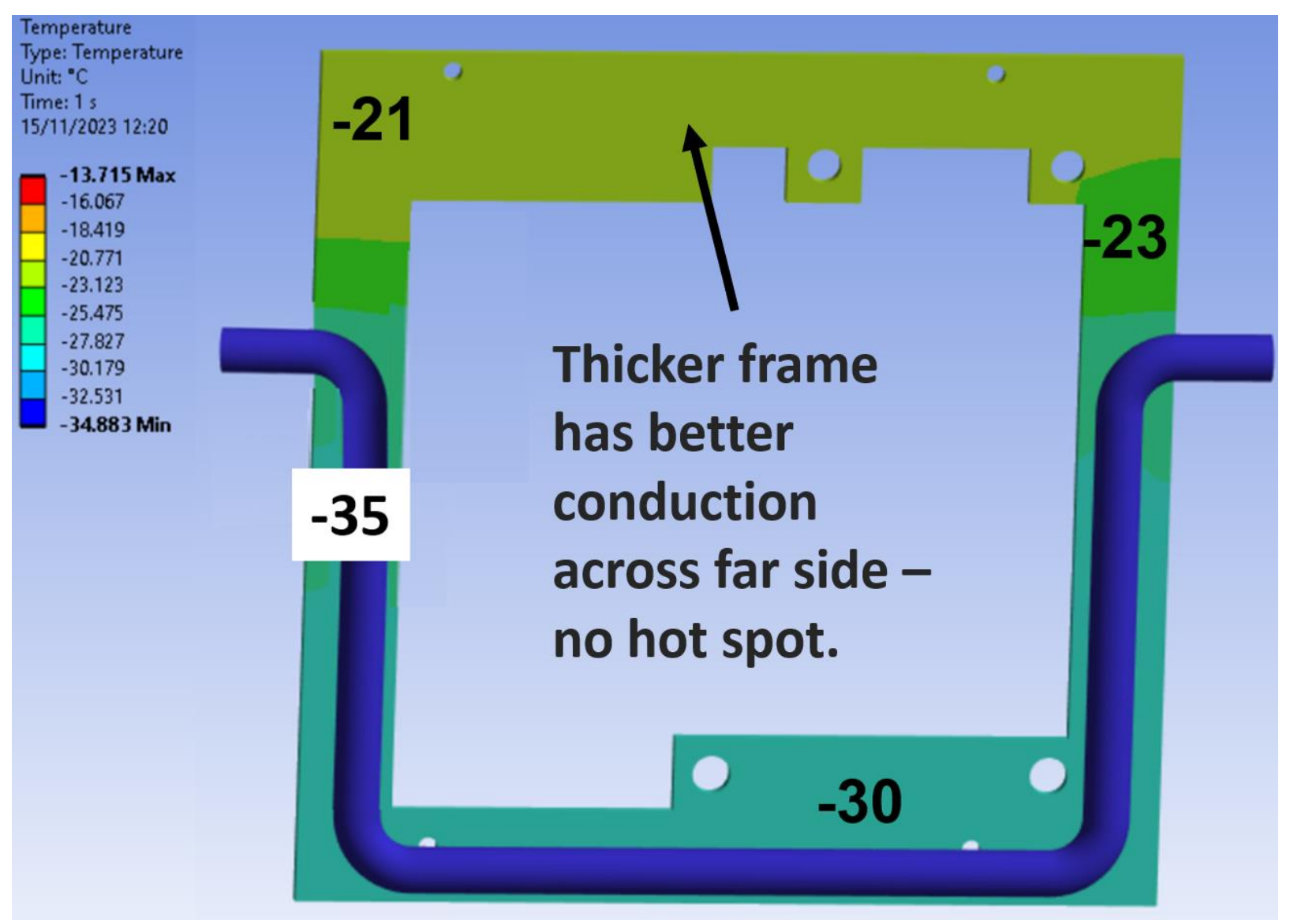


Fig. 4.3: Simulation of **0.8mm Carbon Fiber** frame with banded pipe cooling configuration.

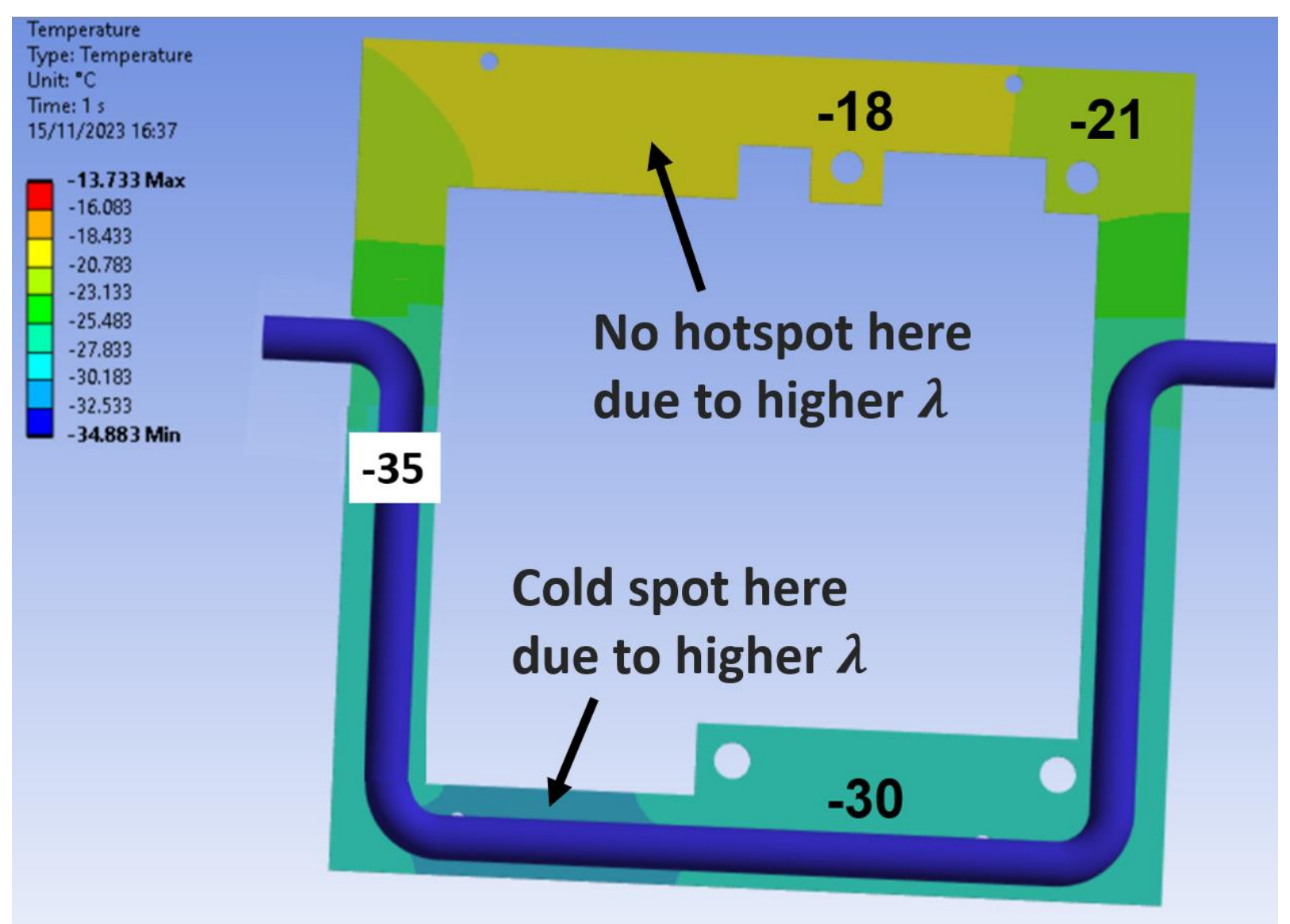


Fig. 4.4: Simulation of **0.4mm Aluminum** frame with banded pipe cooling configuration.

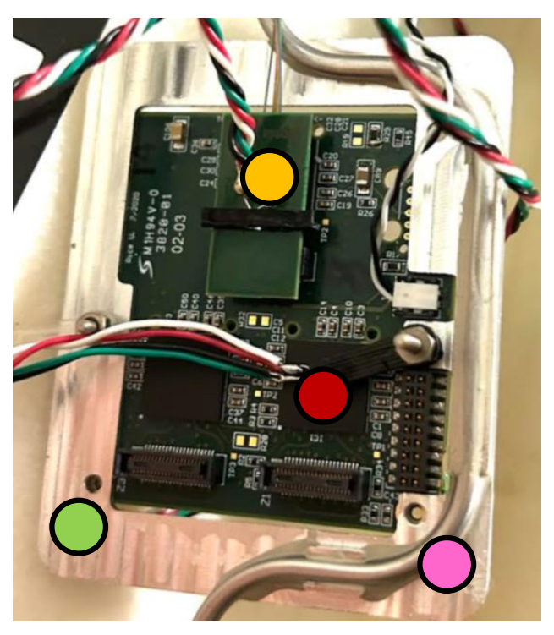
**From simulations, banded pipe ~10℃ cooler on side far from pipe. Carbon fiber and aluminum are similar, so we use aluminum as prototype testing materials. Doubling frame thickness improves cooling conduction across far side.**

## FBCM Thermal Testing in Lab

**PT1000K Thermal Sensors** were attached to the components using 3D printed mounts. The setup was placed in a cold box with dry air flow, and the chiller pumped coolant at **-20℃** through the pipes. The equilibrium temperatures of these components was measured for configurations with straight and banded pipes

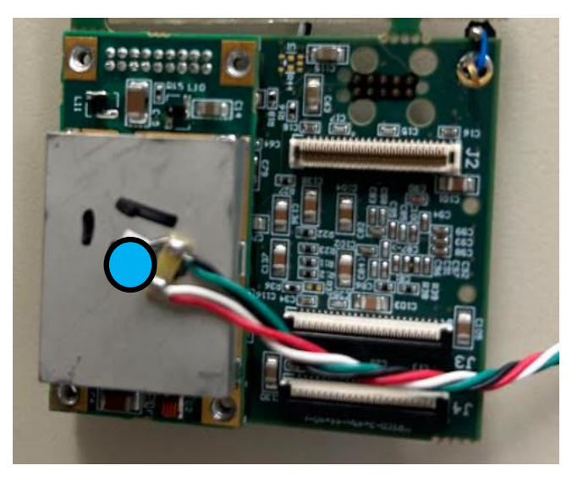
| Component (with powered portcard) | No Cooling – room temp | Coolant -20℃ straight pipe | Coolant -20℃ banded pipe |
|---|---|---|---|
| ● Close to pipe | 51.53 | 8 | -1.96 |
| ● Far from pipe | 51.77 | 15.5 | 4.43 |
| ● VTRX (Top) | 56.16 | 24 | 15.8 |
| ● LPGBT (Right) | 57.59 | 21 | 11.48 |
| ● DC DC | 61.21 | 22.9 | 15.34 |

**Straight Pipe Carbon Fiber**



**Banded Pipe Aluminum**

**New banded pipe configuration keeps all components below 16 degrees – average of 10 degrees lower than old configuration. Agreement with simulation results in Fig. 4.1 & Fig. 4.3.**



**Top Side of Portcard with PT1000K Sensor**

## References

[1] CERN, 2021, "Phase-2 Upgrade of CMS, BRIL Technical Design Report" CERN-LHCC-2021-008.
[2] Kaplon et al., 2023, "The Optimization, design and performance of FBCM23 ASIC for upgraded CMS Beam Monitoring System" Proceedings for TWEPP23 Conference.