Contribution ID: **37** Type: **Oral**

# Lessons learnt from the first vertical slice of the CMS Outer Tracker

*Thursday, 22 September 2022 14:40 (20 minutes)*

A slim vertical slice of the CMS Outer Tracker has been assembled at the Tracker Integration Facility at CERN. It includes the final 2S and PS front-end hybrids with an optical link to the back-end ATCA system, comprising the Data, Trigger and Control (DTC), DAQ & Timing Hub (DTH) and Track Finder (TF). The performance of the system will be described, such as the real-world cooling limits of racks at the Tracker Integration Facility and the CMS Underground Service Cavern; robustness of 25G trigger optical links, readiness of firmware and the first measurements of some key metrics (e.g. latency).

## Summary (500 words)

The DTC communicates to the Tracker 2S & PS hybrids via the CMS Versatile Link, through which it sends the clock & configuration, and receives both trigger data (40MHz) and Level-1 Accept (L1A) data (1MHz). Trigger data is extracted and forwarded over 25G optical links to the Track Finder (TF), which identifies high momentum tracks, determines the track parameters and removes duplicates. Up to 100 tracks per event are extracted from the 200 Tb/s data stream and are sent to the L1 Correlator so that they can be combined with muon and calorimetry information. Both the DTH and TF send L1A data to the High Level Trigger via the DTH, which also supplies fast control and the LHC clock. The DTC, TF and DTH are all ATCA cards that will reside in the CMS Underground Service Cavern, 100m below the surface, where there is limited scope to increase infrastructure. For CMS the racks are expected to host 2 ATCA shelves, each with up to 12 cards. Rack power & cooling is limited to 10kW, which requires operating the ATCA crates at a point to maximise power delivered electronics (as opposed to fans) while still keeping the electronics cool enough for a reliable 10 year lifespan. To put this in perspective, the ATCA fans alone consume more than 30% of allotted shelf power at full speed. The optics are particularly problematic as their temperature must be kept below 50C. Up till now, based on earlier lab measurements, it had been assumed that the heat exchangers would supply air at approximately 20C using cooling water at 16C. Recent studies in the Tracker Integration Facility have shown this not to be the case due to reduced water flow, resulting in air into the shelf at 30C, significantly reducing the thermal envelope for the optics to just 20C. Urgent studies are underway to measure the water flow rate within the CMS Underground Service Cavern racks. Novel approaches to cool up to 200W FPGAs have been devised by several groups, but this paper will present the use of vapour phase chambers to boost the heatsink performance. The 25G, back-end trigger links are a key component of CMS. They do not operate with a FEC to minimise latency, unlike the commercial 100G-SR4 Ethernet standard and are therefore relatively niche products. Up until recently only limited studies have been presented on the robustness of the 25G back-end trigger links. New studies provide insight into the performance of all the different sections of the link (i.e FPGA to optic-tx, optical path and optic-rx to FPGA). Finally, some key system metrics, which have only been possible to measure recently are presented. One of these is the latency from the silicon detector on the hybrid, through the full chain (i.e. from the silicon detector, through readout ASICs and back-end ATCA system, to the Level-1 Trigger).

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**Session Classification:** Systems, Planning, Installation, Commissioning and Running Experience

**Track Classification:** Systems, Planning, Installation, Commissioning and Running Experience