

CMS Tracker Services: current status and potential for upgrade

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Abstract

A report is given on the completed program of installation, connection and testing of the CMS Tracker services, culminating in the full checkout of the Tracker as an integrated system. Finally, in the context of future upgrades to the CMS Tracker, we report also on the potential capacity and constraints of re-using the current services.

I. INTRODUCTION TO THE CMS TRACKER SERVICES

The CMS Tracker is, by far, the largest silicon detector ever built. It has 206 m^2 of active area and is comprised of 15232 modules with over 9.6 million readout channels. To operate the CMS Tracker, a large service infrastructure is required. This infrastructure consists of cooling, data acquisition, and power systems. Each cable, fiber, and pipe must be installed and tested prior to the installation of the tracker.

Table 1: CMS Tracker Infrastructure

Power	2300 Cables
DAQ	3374 Optical Fibers
Cooling	980 Pipes

The tracker uses over 2000 power supply units (PSUs) located in 29 racks throughout the experimental cavern at Point 5 on the Large Hadron Collider (LHC) ring. The DAQ system has 440 Front End Drivers (FED), 80% of all the FEDs used by CMS, located in the service cavern. The cooling system consists of a primary chiller, which was intended to use a brine solution but has now been changed to C_6F_{14} , and two secondary cooling plants that deliver C_6F_{14} to the tracker.

The control and safety systems have been partitioned around the cooling geometry, with the tracker divided into 144 "Cooling Loops" then further subdivided into "Control Groups" and "Power Groups". This structure allows small fractions of the tracker to be tested (and operated) independently.

II. CHECKOUT PROCEDURES

The immense size and complexity of the CMS Tracker and its infrastructure made it necessary to develop systematic testing procedures. Whereas the previous generation of silicon vertex detectors were tested by hand, by a small team, the CMS Tracker testing had to be automated with its progress carefully monitored. This was especially necessary as service installation was done in a tightly managed, overlapping sequence that

distributed the various activities over the whole of the CMS central barrel wheel YB0, managing to work in parallel with other CMS activities, including installation of the electromagnetic calorimeter (ECAL) and heavy lowering of the barrel wheels and endcaps of CMS.

A. PP1 Checkout

The 2300 cables of the power delivery system connect from the power supply racks located on six balconies on either side of the experimental cavern to the Patch Panel 1 (PP1) boards located inside the solenoid. There are 14 PP1 sectors on each side of CMS (plus and minus), and each sector contains five PP1 boards (stacks) that have nine cable connections (places). Each cable end was then labeled with a unique identifier and barcode that showed its connection locations, rack, crate, board, connector for the PS end or sector, stack, place on the PP1 end. The label information is stored in an Oracle database which was used by the software during the checkout. The power cable connection was completed in November 2007 and then began the PP1 Checkout.

To assure that there were no errors in the physical cable map and that all cables were connected properly, a software tool was developed to test each cable and location. Loadboxes, built at Fermilab, were then connected up to five at a time to the PP1 locations. As the power cables also contain lines for the temperature and relative humidity sensors, these were tested by attaching "simulators" that would report a known value. The technician would attach loadboxes and probe simulators for each PP1 location and the automated test would then turn on the appropriate power supply and measure the load. Probe values were read from the PLC, checking the correct value was read at the correct location in the tracker. Each of the two low voltage and two high voltage channels and up to three probes were tested on each PP1 location. The results of each test were then stored in an Oracle database. In this way the PP1 Checkout tool verifies the entire control and power distribution system up to the PP1. This includes the logical map in the database, the physical cable map from PP1 to PSUs, and the cables from PSU to the PLC. Tests for the connection between PP1 and the tracker will be discussed in the following sections.

To monitor the progress of the PP1 Checkout, a web site was developed to show the test results by PP1 location. The web site provided different views, including overviews listing percentage of locations tested successfully, failed tests, and untested locations. Different filters could also be applied to the results to display specific failures (i.e. low voltage, high voltage, missing probe, ...) so the technicians could coordinate repairs by type. As the web pages were dynamically generated from the results

database, the displayed information was always current. After initial installation approximately 5% of cables needed repair.

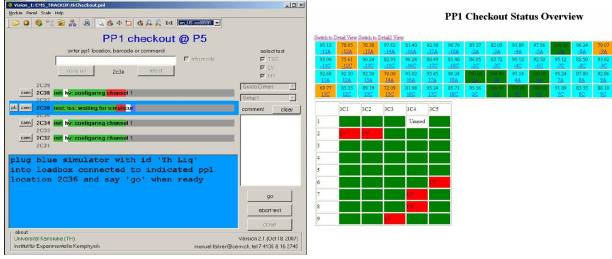


Figure 1: PP1 Checkout tool and status web site.

B. Interlock tests

The Tracker Safety System uses seven Programmable Logic Controllers (PLC) to read out all probes values. Based on the temperatures and humidities, the PLCs can interlock some or all of the power supplies to prevent damage to the tracker. A series of cables run from the PLCs in the service cavern to the power supply racks. This physical map of the interlock cables was tested by a software tool that simulates interlock conditions and verifies that the correct power supplies were interlocked. This test was particularly important because an error in the interlock map would endanger the tracker.

C. Cooling

Before the tracker was connected, one sector of the cooling pipes was tested to -30°C to check the insulation. Also, the two cooling plants were tested. During these tests, a weld in one heat exchanger failed allowing brine to contaminate the C_6F_{14} . This would have been disastrous had the tracker been connected as brine could cause corrosion of the cooling pipes inside the tracker volume.

This resulted in a delay in operating the final cooling system as all contaminated pipes and one plant had to be cleaned. Furthermore, all heat exchangers of this type were replaced and it was decided to replace the brine in the primary plant with C_6F_{14} so another failure of this type would not endanger the tracker.

As a result of this delay, the first two months of the tracker checkout was performed with a temporary cooling plant. The capacity of this smaller plant was such that only four cooling loops could be tested simultaneously.

D. TKCC

The Tracker Connection and Checkout (TKCC) began following the completion of the PP1 Checkout. The TKCC began with the arrival of the tracker at P5 at the end of 2007. Simultaneously, cooling pipes were welded, fibers were attached, and power cables were connected from the tracker bulkhead to the PP1 boards. As connections were completed for each of the three systems it was logged in the database. When all three systems for a cooling loop were connected, that cooling loop was

flagged as ready to be tested.

DCU/PSU Scan The DCU/PSU was the first test, using both the DCS and DAQ, to verify the cable map from the logical name in the database to physical connections from power supplies and FEDs to the detector elements. Each power supply was powered in turn, the DAQ then read out the unique Detector Control Unit (DCU) ID from each module. This ID was then cross-referenced in the database to determine that the correct detector element was indeed powered. Disconnected or faulty power cables would result in no DCU ID being read. Reading a DCU ID that does not match the tested detector element implies a swapped power cable. During the TKCC, less than 20 power cables were found to be disconnected or swapped. In the most severe case, one entire Control Group (8 cables) were determined to be swapped.

The repair of the cable problems was made easier due to the completion of the PP1 Checkout. Since the cable map was verified from PS racks to the PP1 boards, any swaps must have occurred between the PP1 boards and the tracker bulkhead. These cables were then checked at the PP1 and the bulkhead and reconnected if necessary. However, if changing the cable in PP1 or at the bulkhead was difficult or not possible the swap was made at the PSU and the cable was relabeled.

Connection Run The TKCC connection run measured light levels from the optical fibers. This served two purposes, first, to determine that the fiber was connected to the correct location and second, to detect dirty fiber connections. For a well-connected fiber one should see the light level saturate at 1023 adc counts. Fibers with very low light levels were cleaned.

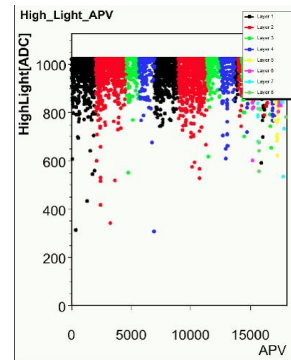


Figure 2: Light levels measured.

Timing Run To account for the differing fiber lengths a latency offset must be determined for each fiber. The latency offset was calculated by the Timing Run. In the Timing Run the lasers were fired simultaneously, the response time was measured, and the offset was calculated. Before the Timing Run the cable structure can be seen, after the latency offsets are applied the latency is strongly peaked at the preferred value of 25 ns.

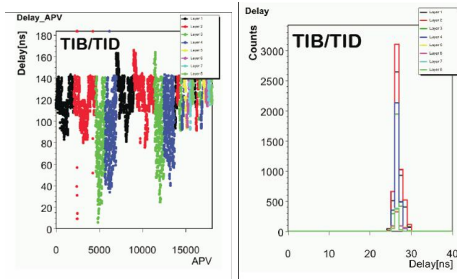


Figure 3: Latency before offset (left), latency after offset (right)

Gain Scan For each optical fiber the laser gain must be set. There is one laser for every two chips on a module. The gain scan is performed by measuring the adc counts with each of the four gain settings. A result of 640 adc counts is considered optimal.

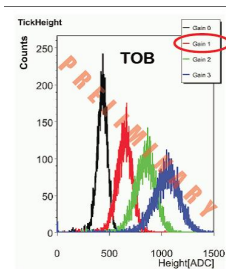


Figure 4: An example of ADC counts for each gain setting

Pedestal Run The Pedestal Run is the final TKCC test and tests the HV, noise characteristics, and storing of pedestals to the database.

III. CURRENT STATUS

With the completion of the TKCC, commissioning using cosmic events began in mid-2008. The tracker participated in several cosmic runs with all of CMS using a global trigger. These runs which took place with the magnet off were known as the Cosmic Run Under ZERo Tesla (CRUZET). There were four weeks of CRUZET runs performed during the summer of 2008 with the tracker joining in weeks three and four. During the tracker's first week participating in CRUZET, over nine million cosmic events were recorded.

First Beams During the first beam event of September 10th, the tracker remained off. This was a precaution to ensure the safety of the tracker in case of a beam accident. Data from the Beam Condition Monitors showed nothing that would endanger the tracker.

IV. SLHC UPGRADE POTENTIAL

As a part of the SLHC Upgrade, the CMS Tracker will be replaced. The services (power, cooling, and fibers) will need to be reused, as many of the services are currently installed beneath other sub-detector (ECAL) services, for which, no upgrade is planned. As the service requirements for the SLHC Tracker are different from the current tracker, the possibilities for reuse are discussed in this section.

A. SLHC Environment

The SLHC upgrade is projected to deliver 10 times the luminosity, but with twice the bunch crossing interval. This results in an expected 400 pile-up events, up from 20, per bunch crossing. Specifically for the tracker, this means there will be ~ 20000 tracks, up from 1000 at the LHC. To reduce the occupancy in the tracker, it is planned to reduce the strip length by at least half, thus increasing the number channels.

B. Power

The two main factors determining the power requirements of the SLHC Tracker are the feature size of the chips, which then sets the operating voltage, and the number of channels. Current designs have many more channels than the current CMS Tracker due to the reduced strip length. A final decision has not been made, but there will be at least twice as many channels and probably much more. However, the SLHC tracker will use chips with a feature size no larger than $0.13 \mu\text{m}$. This smaller feature size then has an operating voltage of 1.2V , roughly half of the current operating voltage. With half the voltage, but at least twice the number of channels, the SLHC Tracker will have a higher total power consumption than the current tracker ($\sim 30\text{kW}$). Smaller feature sizes of $0.09 \mu\text{m}$ and $0.065 \mu\text{m}$ are also being considered and would have an operating voltage of 0.7V .

With a lower operating voltage, but more power used, the currents will be higher, as will the losses. These higher currents exceed the limits of the power cables. As a result, several new powering schemes are being considered.

DC-DC Converters The use of DC-DC converters placed near the tracker bulkhead would allow a higher voltage to be delivered along the power cables, keeping the currents within existing limits. However, electronics placed near the bulkhead would have to be radiation hard and able to operate in a $4T$ magnetic field. It is also necessary to find a low-noise solution. Radiation hard air coils are being considered but the high noise presents a problem. Studies of several designs are currently underway.

Serial Powering A serial power scheme would also keep the currents on the cables within acceptable limits. There are several disadvantages of serial powering that must be considered. Of most concern is that the failure of one module could cause the loss of all the modules in the string. Also, the modules have different grounds.

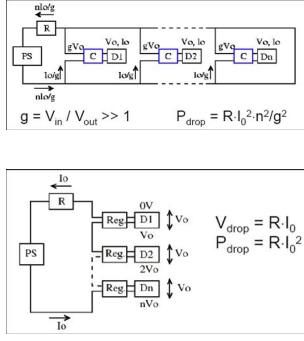


Figure 5: DC-DC scheme (top), serial power scheme (bottom)

C. Cooling

An improved cooling system is being considered for the SLHC Tracker. With the high radiation environment of the SLHC it would be beneficial to operate the tracker at a lower temperature, possibly using coolant at as low as -50°C . This would keep leakage currents down, thus power consumption, and improve beneficial annealing. While several cooling systems have been considered, the favored method is CO_2 cooling.

CO_2 cooling allows for a lower operating temperature, while providing additional benefits. With the lower viscosity of CO_2 smaller pipes may be used inside the tracker, reducing the material budget. Existing cooling pipes are already insulated, which is a requirement for the CO_2 cooling system, so reuse is possible between the plant and the tracker.

V. CONCLUSION

The testing of the CMS tracker services went smoothly. All services, power, fiber, cooling, and safety systems were tested systematically. The only delay was due to the failure of the cooling plant which limited the number of simultaneous tests because of the capacity of the temporary cooling plant. Currently, the CMS Tracker is commissioned and ready for physics with 99.7% of channels operating.

The SLHC upgrade presents new challenges for the CMS Tracker Services. Due to the position of service cables, underneath other sub-detector services, services must be reused. To keep occupancy low with 20 times more tracks, strip lengths must be reduced, increasing the number of channels. New smaller feature size chips help reduce the total power consumption, while increasing radiation hardness, but higher currents exceed existing cable limits. New powering schemes are being investigated that will allow more power to be delivered to the tracker without increasing currents in the existing cables.

The favored cooling system using CO_2 has the benefit of lowering the material budget, while operating at lower temperatures. The location of cooling pipes beneath other sub-detector services make reuse a necessity. This is also true for the fibers, which will also not be able to be replaced easily. In total, the CMS Tracker services have a good potential for reuse with the SLHC Tracker.

REFERENCES

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