On the future of particle physics: Quality control

Samantha Kelly[1], Zhicai Zhang[2], Timon Heim[2]

[1]University of California – Berkeley, [2]Lawrence Berkeley National Laboratory

ABSTRACT

The upgrade of the ATLAS ITk strips detector for HL-LHC will use custom PCBs (powerboards) for on-module DC-DC conversion, HV switching, and monitoring. To ensure high reliability, quality control (QC) testing for the powerboards to be installed on ITk Strip barrel modules is necessary. This paper will present the QC procedure used for the powerboards. Before module assembly, each powerboard must pass QC tests, including thermal cycling, burn-in, and electrical tests of the low voltage (LV), high voltage (HV), and monitoring functions of the powerboard. The ATLAS group at LBNL developed a massive test crate that can perform electrical and thermal tests on 200 powerboards simultaneously. This test crate is crucial for the timely delivery of this component of the upgrade and is affixed with an interlock system to ensure the safety of powerboards in testing. The production procedure and QC test system has been tested with 500 powerboards during Pre-Production B Batches 4 and 5, and the system has been proven ready for production with the desired testing program, speed, safety, and cost. Unanticipated failures and abnormalities in powerboard test results are also presented.

HL-LHC UPGRADE

High Luminosity Large Hadron Collider (HL-LHC)

- All-silicon inner tracking (ITk) detector with strip system
- Silicon sensors are very radiation tolerant and have higher granulation
- Strip barrel modules need powerboards for DC-DC conversion, HV switching, monitoring
- Powerboards must be reliable

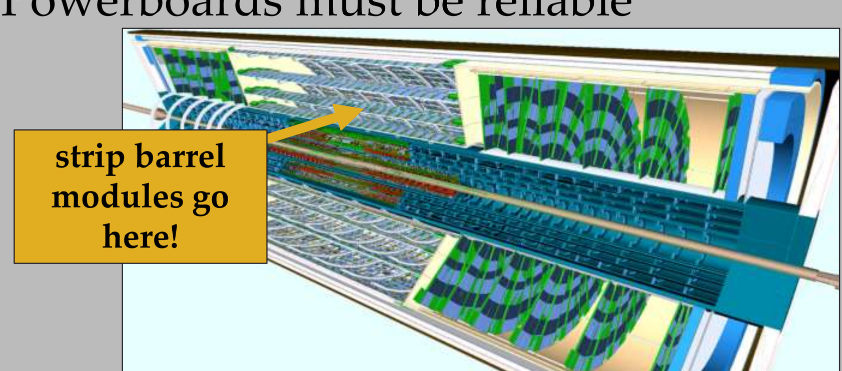

Figure 1: Layout of Inner Tracker (ITk)
Credit: CERN-LHCC-2017-005, pg. 19

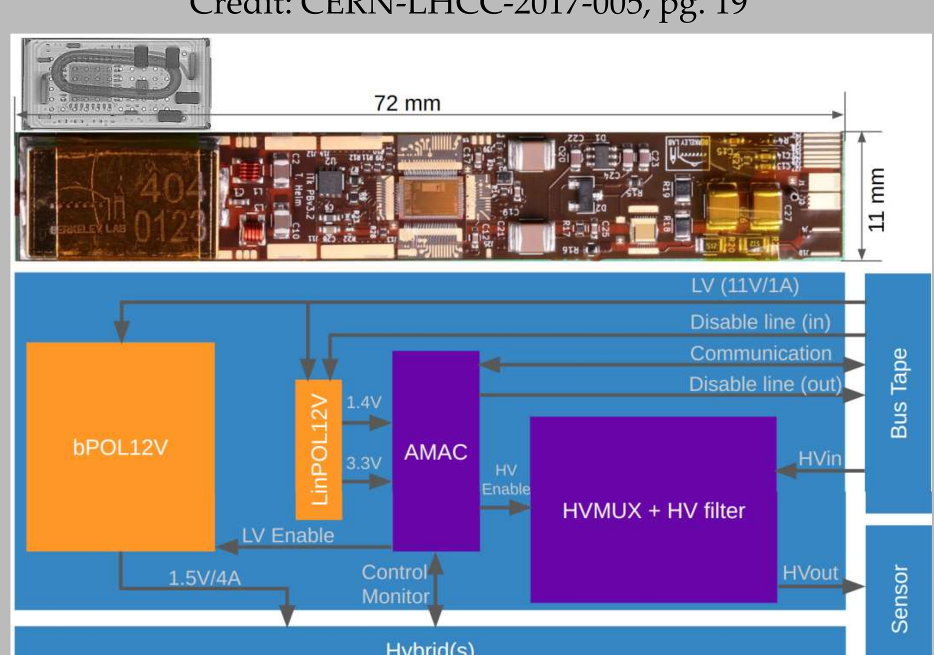

Figure 2: Top: a powerboard, with an X-ray image of the area under the shield box. Bottom: a simplified schematic diagram of the powerboard design
Credit: ATL-COM-ITK-2022-104, pg. 2

TEST CRATE

- ***Objective:*** Quality control (QC) testing → Reliable powerboards
- ***Challenge:*** QC testing → Many tests to run on 14000 boards
- ***Solution:*** Test in parallel with a crate!

TEST CRATE

Thermal Cycle Crate

- Massive test crate simultaneously tests 200 powerboards (passive side)
- Daisy-chained active boards (reusable PCBs) host testing circuits, receive/store output signals from powerboards (active side)
- Electrical tests run at warm and cold temperatures after different exposures
- Graphical user interface (GUI) used to execute many tests automatically during electrical testing
- Updated crate construction underway in preparation for production

Figure 2: Massive test crate (active side)
Credit: Zhicai Zhang

QC PROCEDURE

Database registration
Visual inspection
Load the crate. Turn on chiller, set to 20 °C
Electrical test (full) – warm
Upload test result
Cool down to -35 °C
Electrical test (full) – cold
Upload test result
Thermal cycle
Electrical test (full) – warm
Upload test result
Burn-In
Electrical test (full) – warm
Upload test result
Cool down to -35 °C
Electrical test (full) – cold
Upload test result
Warm up to 20 °C and turn off chiller. Then unload the crate
Duration: appx. 60 hours of chiller on appx. 4.5 days of real time

- All steps integrated in all-in-one custom web-based GUI
- Communicates with System-on-Chip boards for electrical testing, with the chiller for thermal cycling, and with the ITk production database for uploading data
- Monitors tables and graphs for testing results and crate status

QC PROCEDURE

Database Registration & Uploading

- Tests results are uploaded to central ITk database using integrated GUI

Visual Inspection

- High resolution pictures taken of each board
- Boards inspected for missing/tombstoned components, missing/broken wirebonds, incomplete seams on the shield box, solder splash on the bond pads, etc.

Thermal Cycling

- Chiller temperatures cycled between -35 °C and 40 °C three times

Burn-In

- DC-DC converter loaded at 2 A for 24 hours without interruption
- Crate set to 20 °C for entire burn-in duration

Electrical Tests

- Performed before, after, and between thermal cyclin and burn-in
- Includes functionality tests and characterization graphs

Functionality Tests

- Include LV and HV ON/OFF measurements and function of Autonomous Monitor And Control (AMAC) chip designed to monitor voltages/currents/temperatures and control power to front-end electronics

Characterization Graphs

- Include LV, HV, and AMAC settings (e.g. scan of DC-DC converter efficiency, temperatures, or currents at different loads)

TEST RESULTS

- 500 boards tested with QC system during pre-production
- 97.4% passed QC with no issues (yield within acceptable range)
- All other boards passed with no issues
- Typical failures include AMAC communication issues, unexpected DC-DC efficiency at certain loads/temperatures, failure of other sensors (e.g. temperature) on board

DC-DC Efficiency Drop-Off at 1 A During Cold Electrical Tests

- 3 pre-production boards failed
- Not observed by chip designer

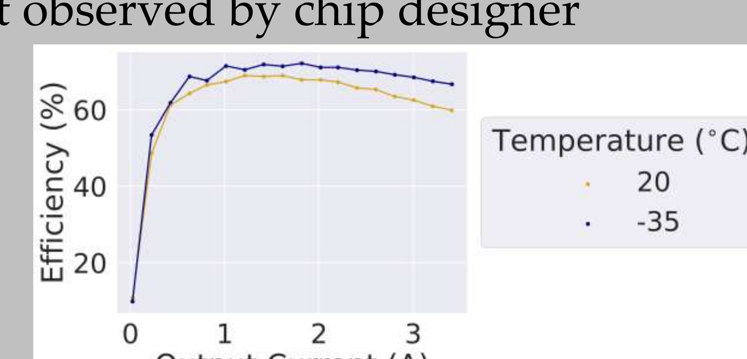

Figure 4: DC-DC Efficiency for passing board

TEST RESULTS

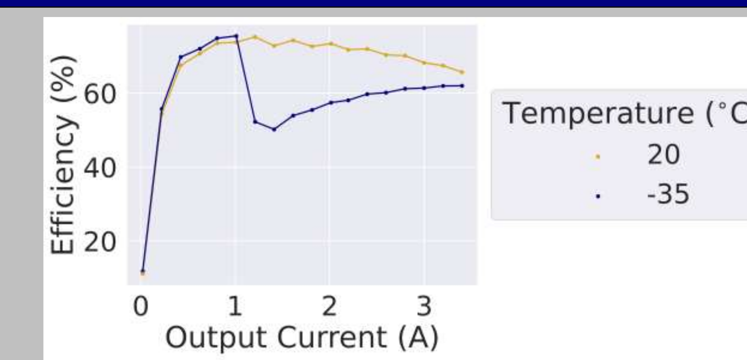

Figure 5: DC-DC Efficiency for abnormal board

- ***Hypothesis:*** Increased input current → Decreased DC-DC efficiency
- Chip designer notified and investigating this issue

Discontinuity at 750 Counts in AM Response Graphs During Cold Electrical Tests

- 348 boards with accessible data were analyzed
- AM Response graph shows calibration of analog-to-digital converters (ADCs) in AMAC chip by injecting known voltage (x-axis) and reading out ADC counts (y-axis)
- Graph should be linear and continuous
- 171/348 boards (49%) exhibited AM Response abnormalities only at cold temperatures
- ***Cause:*** technology transition in AMAC
- Does not result in QC failure
- Two types of discontinuity: "jump" and "stuck"

Stuck

- 42/348 boards (12%) get "stuck" at 750 counts

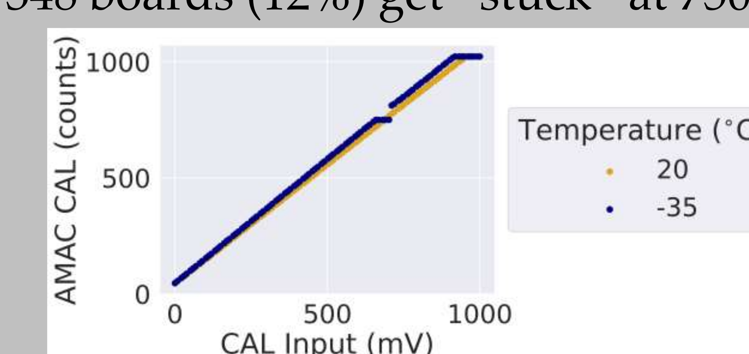

Figure 6: AM Response for "stuck" board

- Board "stuck" if 2+ consecutive measurements of 750 counts

Jump

- 129/306 (42%) "jump" over 750 counts

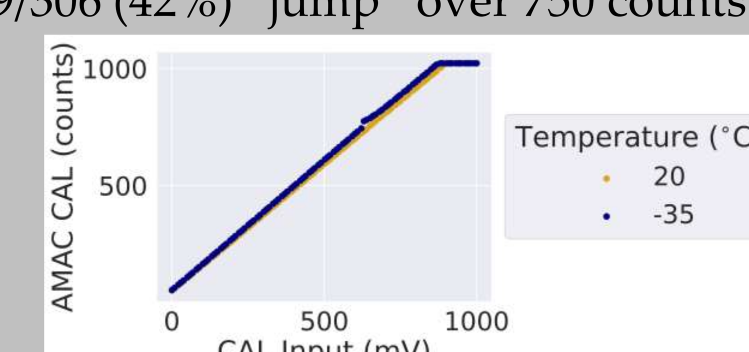

Figure 7: AM Response for "jump" board

- Board "jump" if a) not flagged as "stuck", b) step between n-th and (n-1)-th AMAC CAL value is greater than double the step between (n-1)-th and (n-2)-th, c) (n-2)-th greater than 750 counts, d) n-th less than 750 counts

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