Thermal Stability Analysis of ATLAS TileCal Phase-II Upgrade Low Voltage Power Supply in Production Burn-in Testing.

Edward Nkadimeng, Ryan Mckenzie, Sanele Gumede, Mukesh Kumar, Thapelo Leboho, Vuyolwethu Kakancu, Njokweni Mbuyiswa, Bruce Mellado, Donald Ngobeni, Lungisani Phakathi, Vongani Chabalala, Thabo Pilusa, Tshepang Pule, Roger Van Rensburg.

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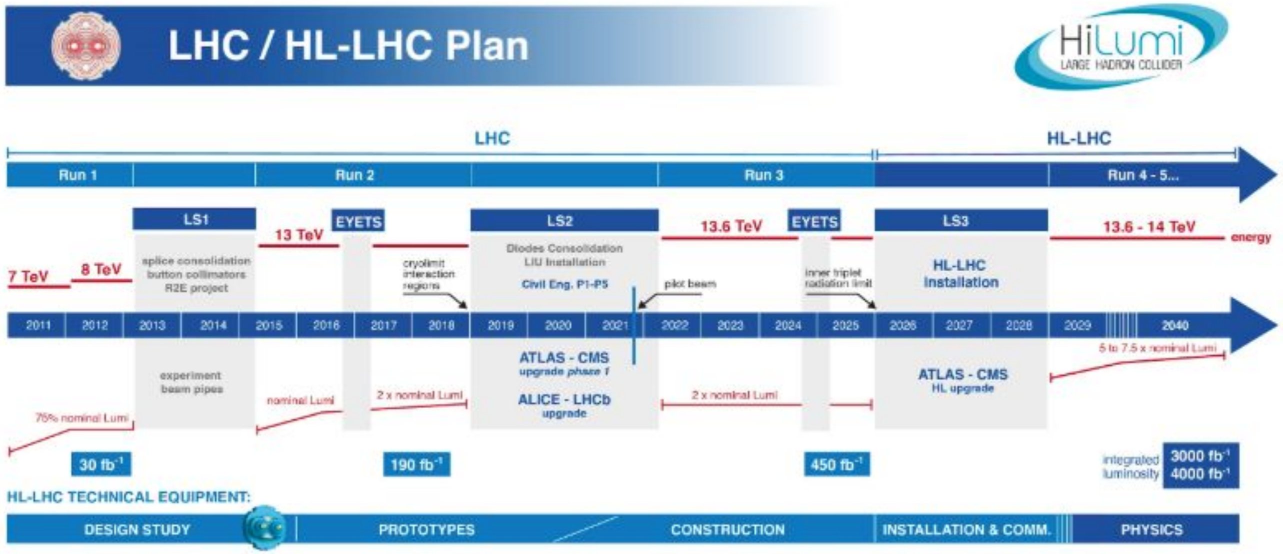
Introduction

The Motivation: Higher luminosity improves physics reach, but it increases detector stress, pile-up and radiation exposure.

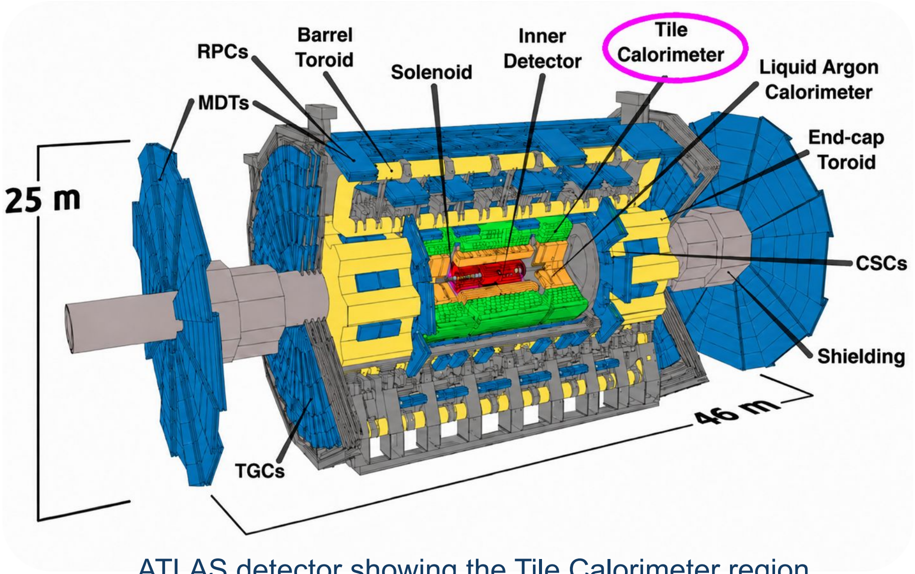
Run 4 / HL-LHC environment



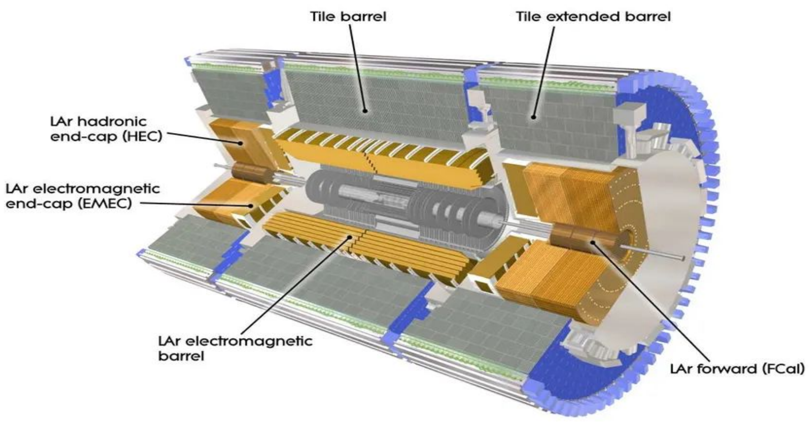
7.5×10^{34} $cm^{-2}s^{-1}$	~200	2026
expected peak luminosity	pile-up / crossing	long-shutdown start

- The LHC undergoing upgrade to HL-LHC
- Instantaneous luminosity increases by a factor of about 5–7 compared with current LHC running conditions.
- Pile-up grows from ~50 to ~200 collisions per bunch crossing, increasing detector occupancy and data throughput.
- Electronics must remain stable for many years in radiation, magnetic-field and limited-access conditions.

The ATLAS Tile Calorimeter



ATLAS detector showing the Tile Calorimeter region

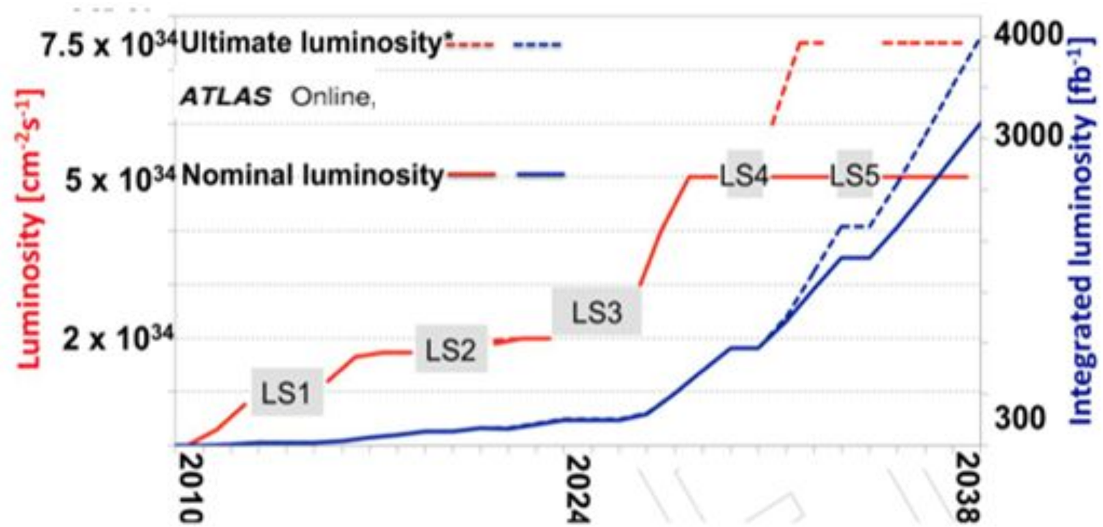


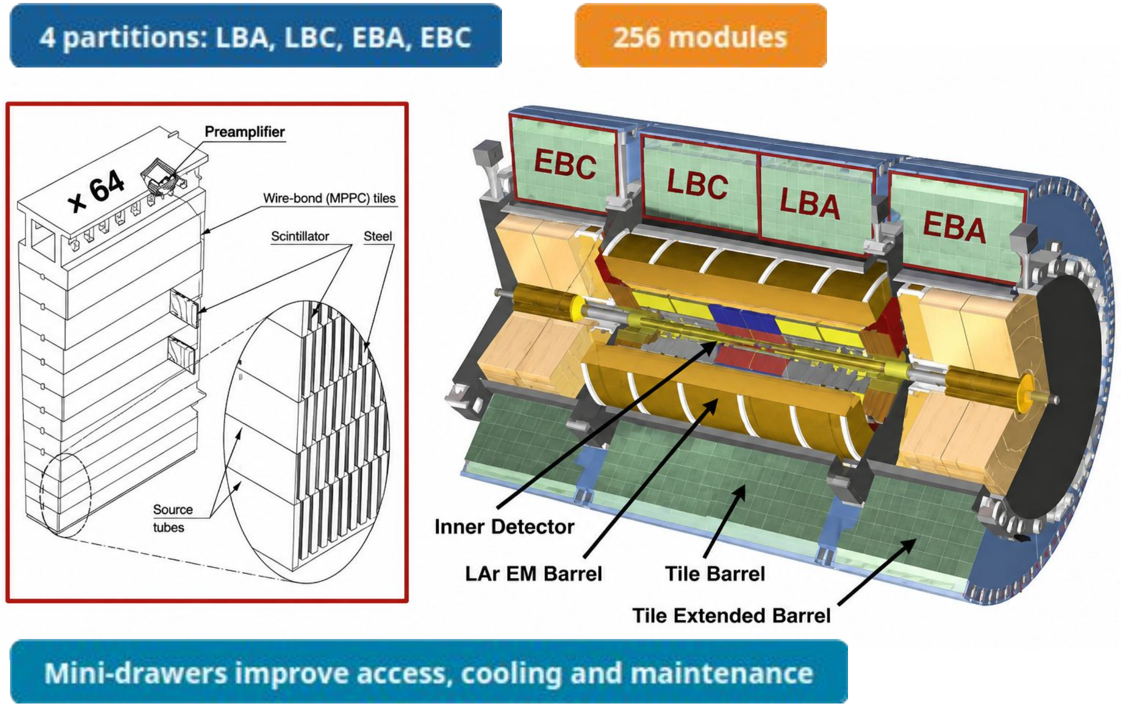
Tile Calorimeter structure

- **ATLAS role**: a general-purpose LHC detector that reconstructs particles using tracking detectors, calorimeters and the muon spectrometer.
- **TileCal role:** the central hadronic calorimeter; it measures hadrons and jets and contributes to the missing transverse energy and hadronic tau measurements.
- TileCal is a sampling calorimeter: steel absorber plates create particle showers, while plastic scintillator tiles produce light proportional to the deposited energy.
- The scintillation light is transported by wavelength-shifting fibres to Photomultiplier Tubes (PMTs), where it is converted into electrical signals for readout.
- Reliable readout depends on stable on-detector electronics, cooling systems, and power delivery during long-term ATLAS operation.
- This motivates the study of the Tile Calorimeter Phase II upgrade, which must remain reliable under HL-LHC conditions.

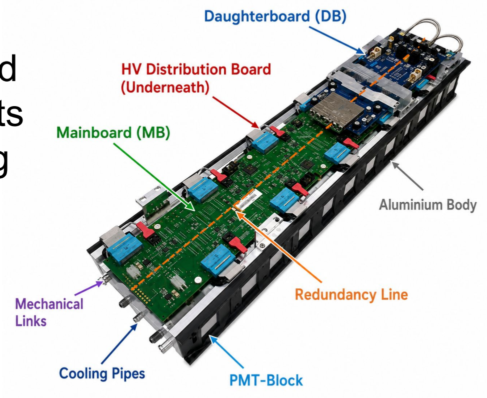
The Tile calorimeter Phase II upgrade

- The HL-LHC operation, TileCal readout electronics are replaced for of long-term reliability with increased luminosity.
- Involves increasing the radiation hardness for handling a maximum total integrated radiation dose ~400 Gy of TID, 4 x 1012 n/cm2 of NIEL and 2.5 x 1012 p/cm2 of SEE estimated for long operation.
- Complete replacement of on detector and off detector readout electronics.
- Full digital readout for trigger and data acquisition at the LHC bunch-crossing rate.
- Mini-drawer mechanics improve access, cooling support and maintenance.
- PMT blocks, HV dividers and calibration systems are upgraded for HL-LHC operation.





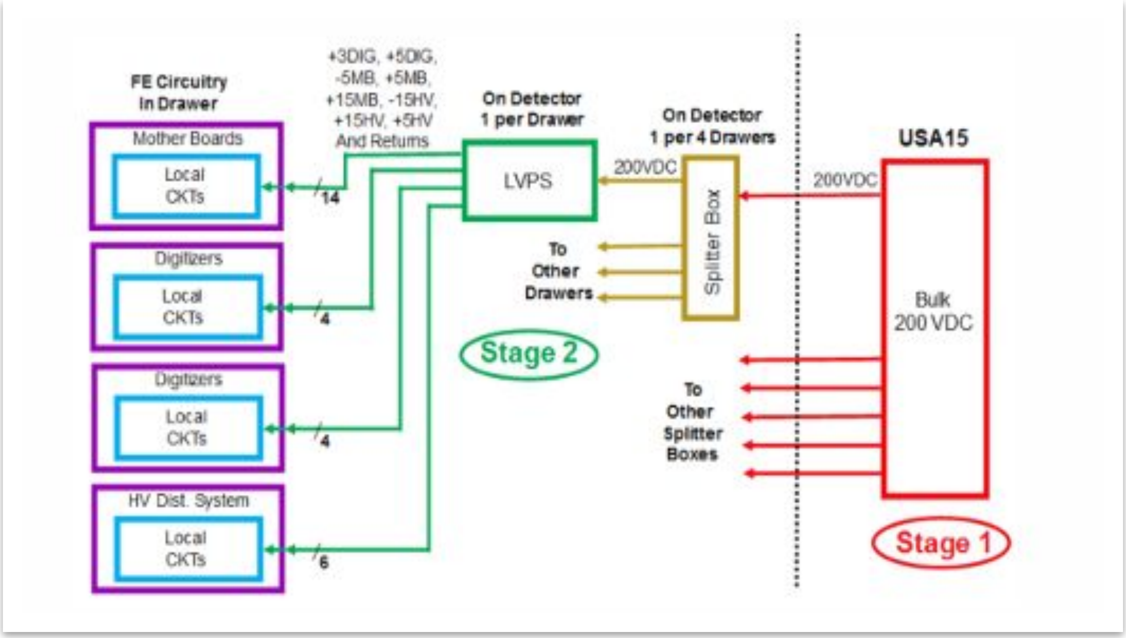
The new drawer mechanics package the photomultiplier tubes and front-end electronics in smaller, serviceable units with improved mechanical and cooling support.



Tile Calorimeter Low Voltage Power Supply Systems

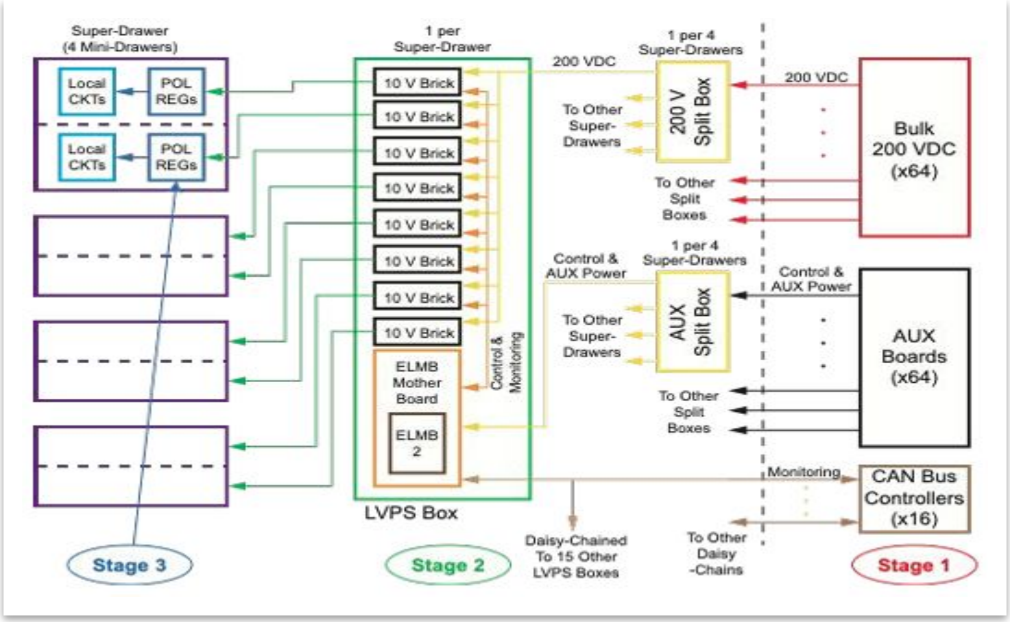
Low-Voltage System

- A TileCal LVPS PCB, contains 8 transformers as well as several other pieces of supporting hardware.
- A 2-stage system in which Bulk 200 VDC power is converted to the voltages required by the on-detector electronics by different types of Board.
- Provides ON/OFF control (Via Aux-boards) of the board in two groups which start successively.



The upgraded Low-Voltage System

- Conversion to a 3-stage system which makes use of Point-of load regulators (POLs). POLs function to step-down the 10 VDC received from an LVPS Brick to the voltage required by local circuits. This allows for the use of a single type of board with a standardized 10 V output
- Tri-state functionality is being introduced which allows for individual Board startup/shutdown. This functionality is due to the Aux-boards ability to send 3 different state signals to an LVPS Brick.

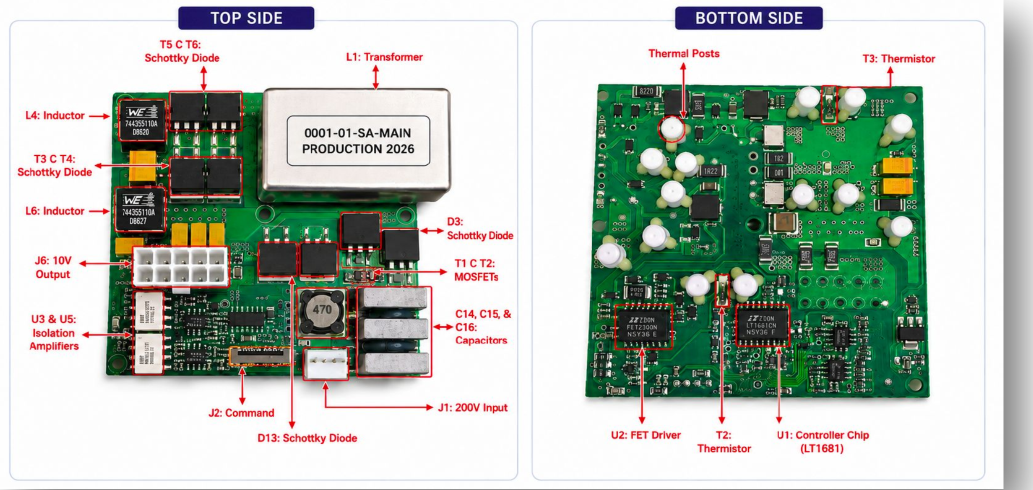


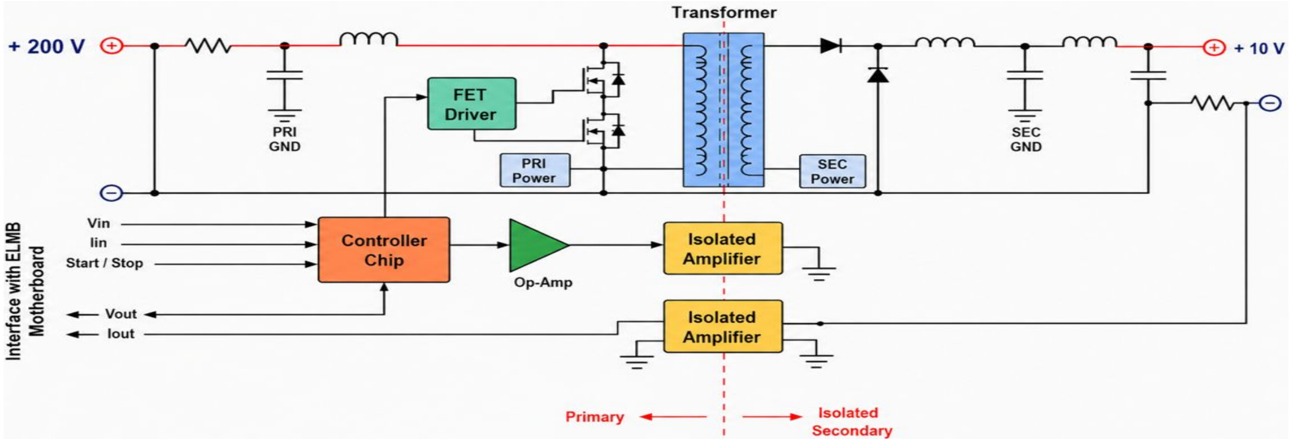
Low Voltage Power Supply Board

Transformer-coupled buck converters reduce +200 V DC to regulated low-voltage output for TileCal electronics.

Principle on operation

- Transformer coupled buck convertor know as forward converter
- Controller chip is used to provide switching at frequency of ~ 300 kHz
- Field Effect Transistors (FET's) when conducting current flows to the primary windings of the transformer which transfers energy to the secondary windings.
- Opto-Isolators: Provide voltage feedback.
- Shunt Resistor: For measuring the output current.
- Protection circuitry: Over Current Protection , Over Voltage Protection, Over Temperature Protection.





- **Features:**
  - – Custom built, compact.
  - – Water cooled using Al_2O_3 components;
  - – 10 V Board, 2.3 A
  - – Environment: Magnetic field; Radiation tolerant.
  - – Efficiency target: 80%

LVPS Board Quality Control Procedure

The LVPS board production testing procedure is designed to verify that each board satisfies its required design specifications before it is accepted for use. The procedure also helps identify defective or unstable board early, improving the overall reliability of the TileCal low-voltage power system.

- Production testing is carried out using two main test systems: the single-board test station and the burn-in test station.
- The single-board test station is used for initial electrical testing. At this stage, key performance parameters such as output voltage, current behaviour, and correct start-up operation are checked.
- The burn-in test station is then used to operate the board under controlled load and temperature conditions for an extended period. This helps expose early-life failures that may not appear during short functional tests.
- After burn-in, a final test is performed to confirm that the board still operates within its design specifications.
- Only board that successfully pass the full testing chain are accepted for the next production stage, including LVPS box assembly and eventual shipment for detector integration.

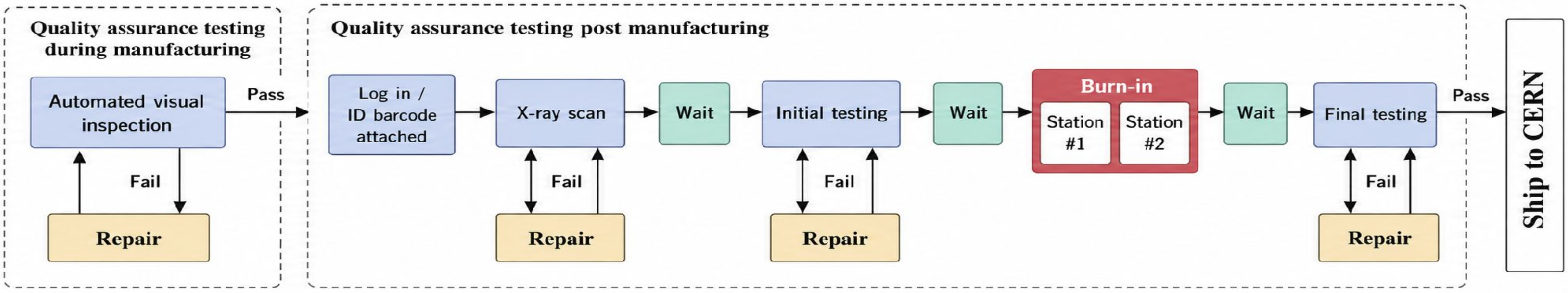


Fig. Block diagram of the Brick checkout procedure.

Burn-in Test Stations

Production burn-in is a reliability screen: it stresses each LVPS Board under controlled load and temperature before detector installation.

- Reveal early-life defects that may not appear during visual inspection or a short functional test.
- Stimulate realistic failure mechanisms such as high operating temperature while staying below OCP, OVP and OTP limits.
- Confirm that temperature, voltage and current remain stable during the soak period.
- Reject weak Bricks before installation in the inaccessible ATLAS TileCal environment.

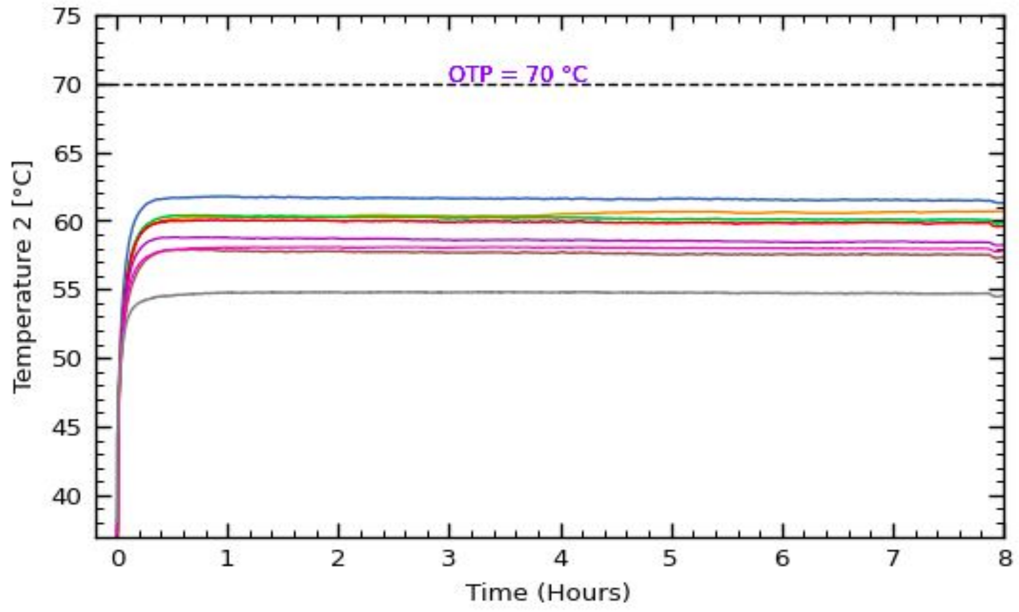
❑ LVPS Board inside the Burn-in station

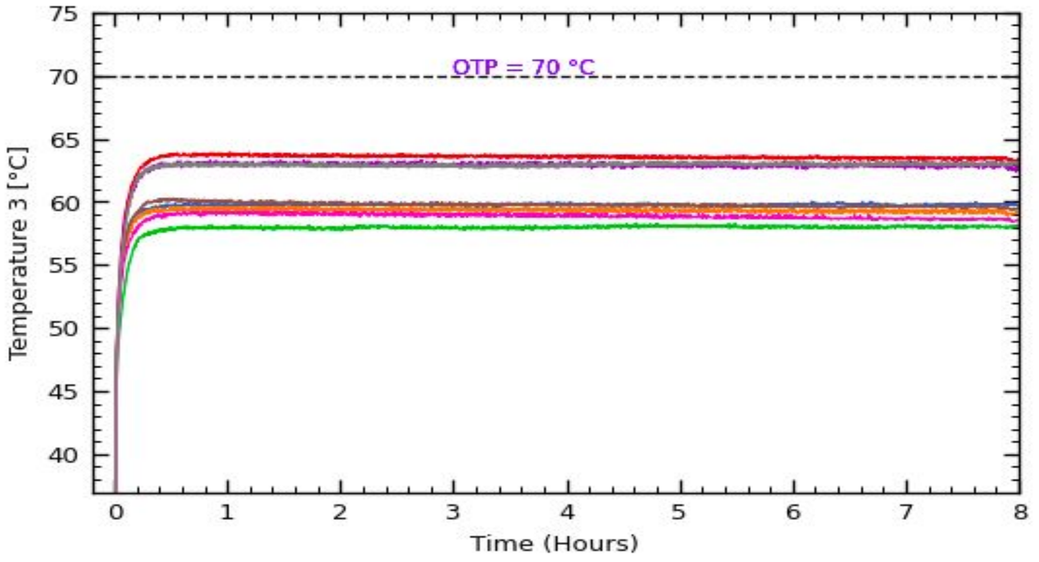
Origin	Measurements
Board	Vin, Vout, Iin, Iout, T2, T3
Dummy load	Vload, Iload
DC supply	Station Vin, station Iin

Parameter	Burn-in	Nominal	Protection
Operating temp.	60 °C	35 °C	70 °C OTP
Applied load	5.0 A	2.3 A	6.9 A OCP
Output voltage	10 V	10 V	11.85 V OVP
Run-time	8 h	—	—

Burn-in result: stable T2 and T3 behaviour

Temperatures of the Board
Simultaneous Burn-in

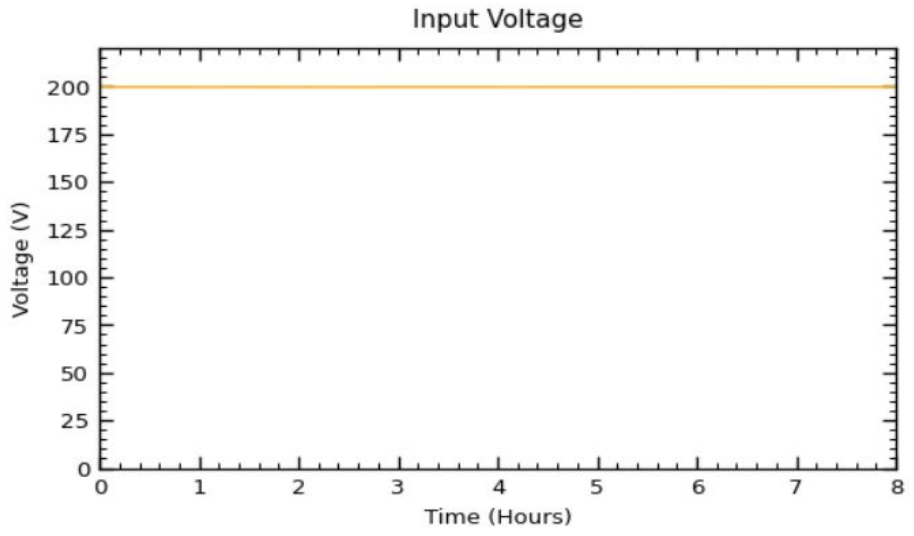


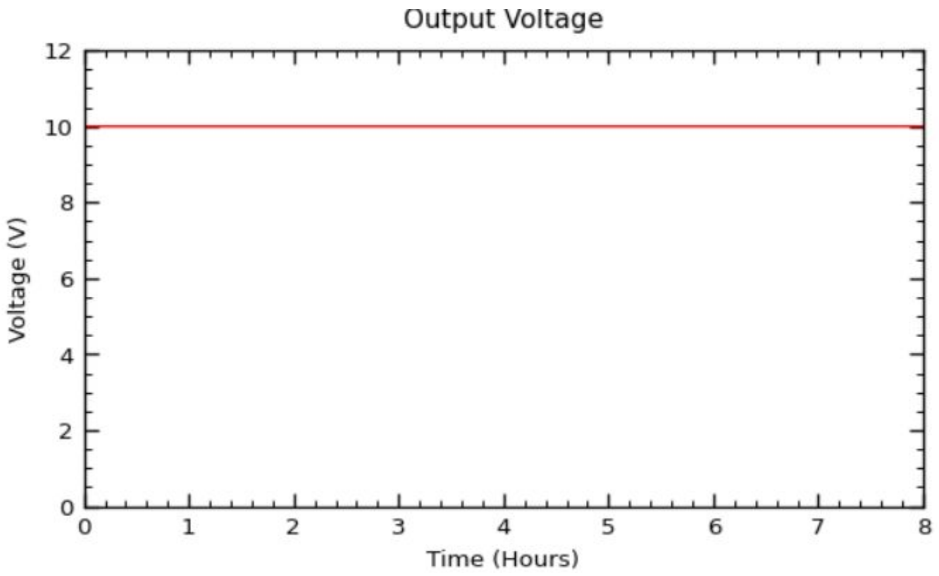


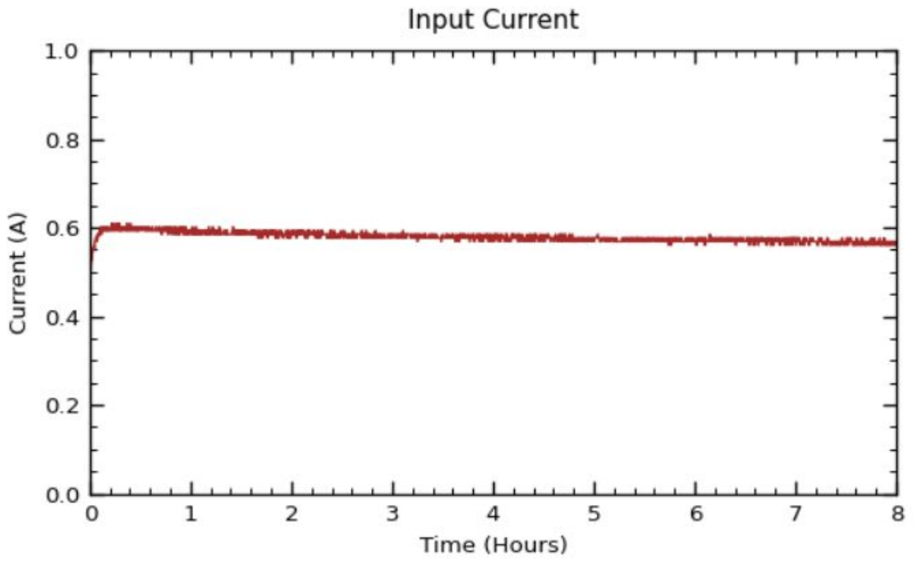
Boards observed behaviour

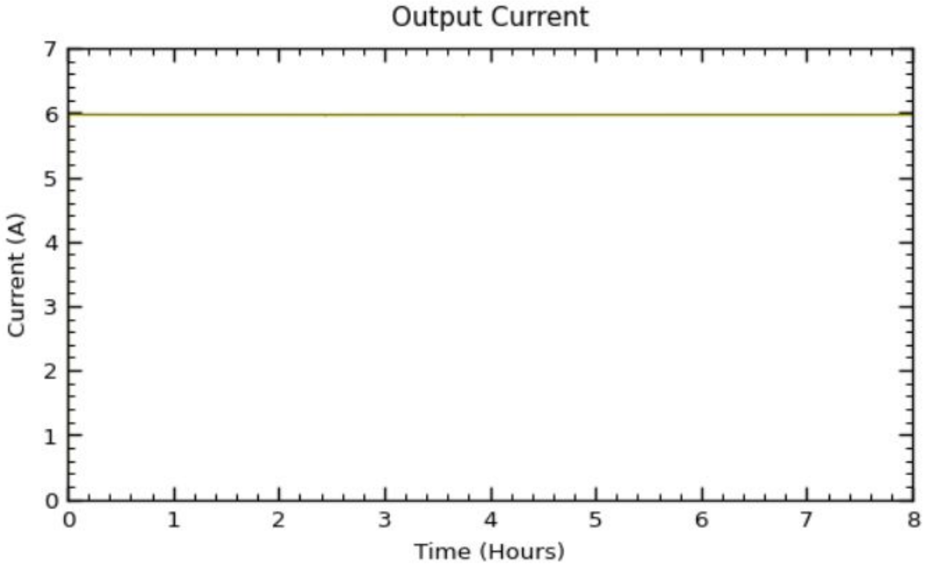
- T2 rapidly rises to about 60 °C and remains stable across the 8 h burn-in.
- T3 stabilises around 55–60 °C, .
- The T2 and T3 separation is consistent with thermistor/component placement.
- No thermal runaway is observed; the Boards remains below the 70 °C OTP limit.
- **Rise**: Boards is switched on and loaded at 6 A while temperature increases.
- **Soak**: Temperature is held around 60 °C for reliability stress.
- **Fall**: Brick is switched off and allowed to cool after the burn-in run.

Electrical Quantities Monitored in Burn-in







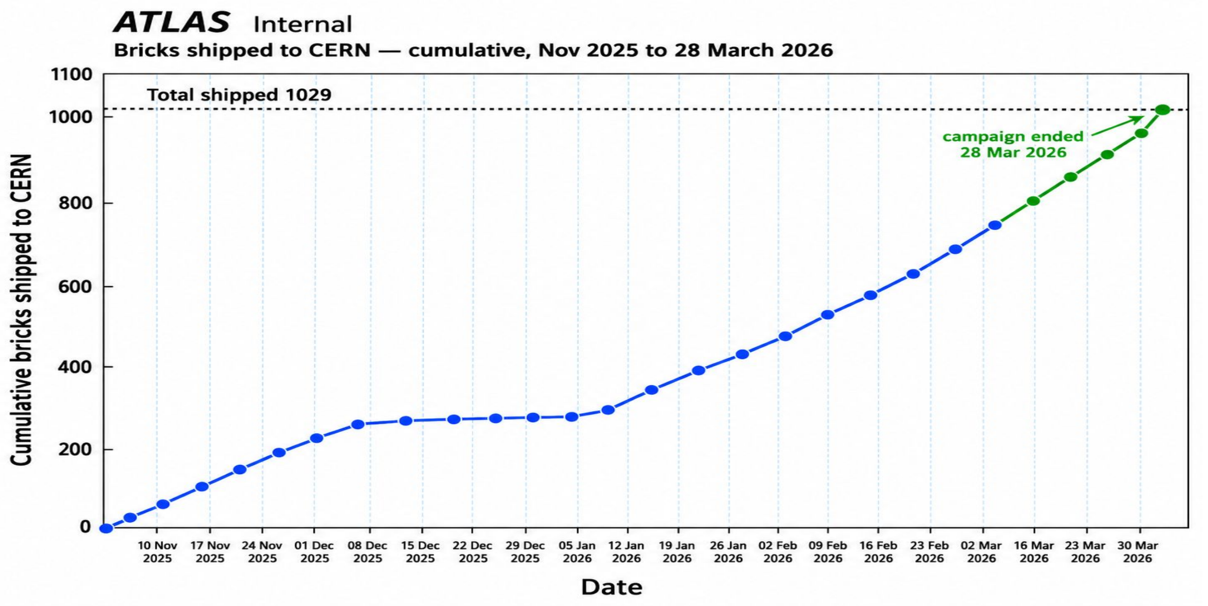


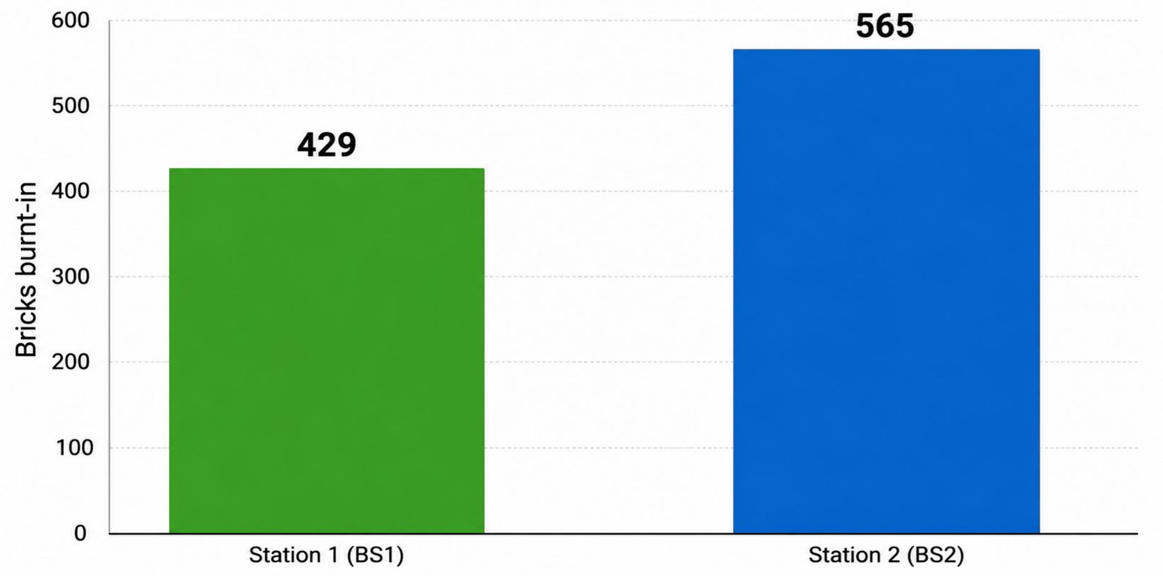
Main Production of the LVPS Boards

TileCal Phase-II LVPS production programme, including the manufacturing, quality control and final qualification of the LVPS board.

Burn-in Test Campaign Summary

- 1029 produced for main production.
- 16 LVPS Boards did not undergo the QC procedure (Faulty Boards)
- 19 LVPS Boards went for Partial QC procedure.
- A total of 994 bricks were successfully burn-in tested using two parallel burn-in stations:
  - Station 1 (BS1): 429 Boards burnt in.
  - Station 2 (BS2): 565 Boards burnt in.
- The BS1/BS2 difference between reflects station uptime during the November – March campaign, although both stations were operated in parallel throughout the testing period.
- Total of 35 Bricks not completely went through the full QC procedure, representing about 3.4 % of the Main production





Summary and Outlook

- The ATLAS TileCal Phase-II upgrade requires a reliable low-voltage power system capable of operating under HL-LHC conditions.
- Burn-in testing is used as a production quality-control step to identify weak or unstable LVPS bricks before installation.
- The tested LVPS bricks show stable thermal behaviour, with T2 and T3 remaining below the 70°C over-temperature protection limit.
- The temperature profile follows the expected behaviour: rise during start-up, stable soak during burn-in, and cooling after switch-off.
- Electrical quantities such as input current and efficiency provide additional confirmation of stable brick operation.
- Assemble the qualified LVPS bricks into the complete LVPS box.
- Verify the mechanical integration of the LVPS box, including cooling plate contact, cabling, fuse board, ELMB monitoring board, and internal connections.
- Perform thermal testing of the fully assembled LVPS box under realistic operating conditions.
- Study heat transfer and temperature distribution across the complete LVPS box during operation.
- Compare LVPS box thermal behaviour with individual brick burn-in results.
- Confirm that the assembled LVPS box remains thermally stable and below protection limits before final acceptance and detector installation


Thank you
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