A Burn-in Apparatus for the ATLAS Hadronic Tile- Calorimeter Phase-II Upgrade Transformer- Coupled Buck-Converters

Technology and Instrumentation in Particle Physics (TIPP2023)

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ATLAS Hadronic Tile-Calorimeter

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Talk Outline

The ATLAS Hadronic Tile-Calorimeter

- The Hadronic Tile-Calorimeter (TileCal) is a sampling calorimeter which forms the central region of the Hadronic calorimeter of the ATLAS experiment.
- It performs several critical functions within ATLAS such as the measurement and reconstruction of hadrons, jets, hadronic decays of τ -leptons, and missing transverse energy. It also participates in muon identification and provides inputs to the Level-1 calorimeter trigger system.
- TileCal is composed of 256 wedge-shaped modules which are arranged azimuthally around the beam axis. A module consists of alternating steel (absorber) tiles and plastic scintillating tiles (active medium) with a Super Drawer (SD) housing the Front-End (FE) electronics and the Photomultiplier tubes located on its outer radius.

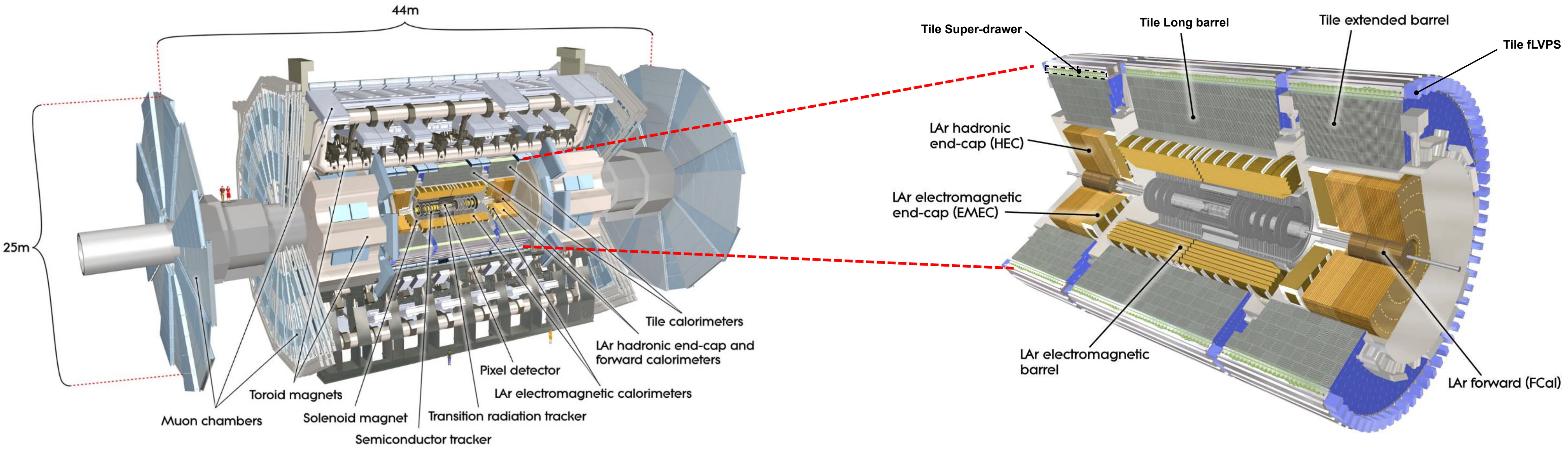

***Fig.1 The ATLAS detector (Left). The ATLAS inner Barrel (Right)** -J. Pequenao, Computer Generated image of the ATLAS calorimeter,(2008), https: // cds. cern. ch/ record/ 1095927*

TileCal Phase-II Upgrade Overview

- In the year 2029 the start of the operation of the **High-luminosity Large Hadron Collider (HL-LHC)** is planned .
- **TileCal will be upgraded** to ensure peak performance within the HL-LHC environment.
- **New Front-end and Back-end electronics** - to stream data to trigger processor at 40 MHz crossing rate providing fully digital data to the trigger processors.
- **Replacement of 10% of PMTs** associated with the most exposed cells.
- **New mechanical frames** to house the front-end electronics.
- **HV**(PMT) will be controlled remotely.
- **LV**: Unified Input to FE electronics power to 10V, individual Brick On/Off control. See ref slide pg
- **Upgraded calibration systems** (Cesium and Laser).
- **Redundancy introduced in data links**;
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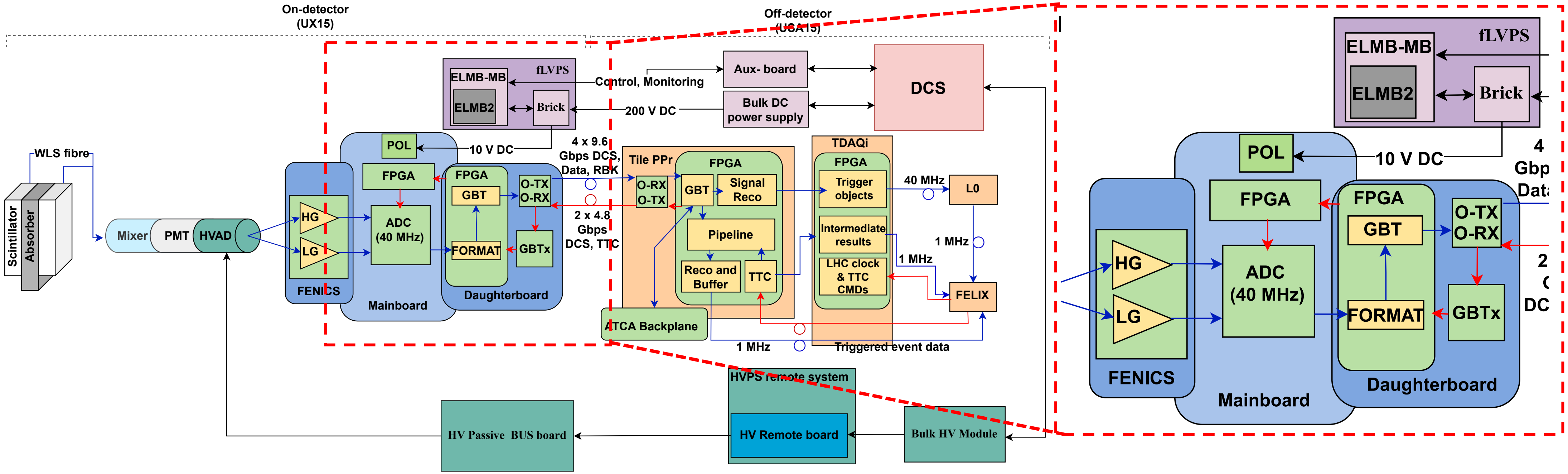


Finger Low-Voltage Power Supply (2nd stage)

FE = Front-End
ELMB = Embedded Local Monitoring Board
ELMB-MB = ELMB Mother-Board

- 256 fLVPS within the TileCal (1 per module).
- Provides LV power to the FE electronics.
- Allows for power cycling of FE electronics.

Composed of:

- 8 Transformer-coupled buck converters (Bricks).
- ELMB2 mounted on ELMB-MB.
- Fuse board
- Cooling plate.
- Chassis

Component	Function
	Power distribution
Bulk 200 VDC	Input power
10 V Bricks	Convert 200VDC to 10VDC for FE electronics
Internal LV cable	Distribute the 10V DC to FE electronics
	Brick control
Auxiliary board cable	Transmit brick on/off signals from USA15
ELMB Motherboard	On/off control of bricks
	Monitoring
CanBus	Remote communication with ELMB2
Auxiliary board cable	Power to ELMB2
ELMB2	Temperature, voltage, current monitoring

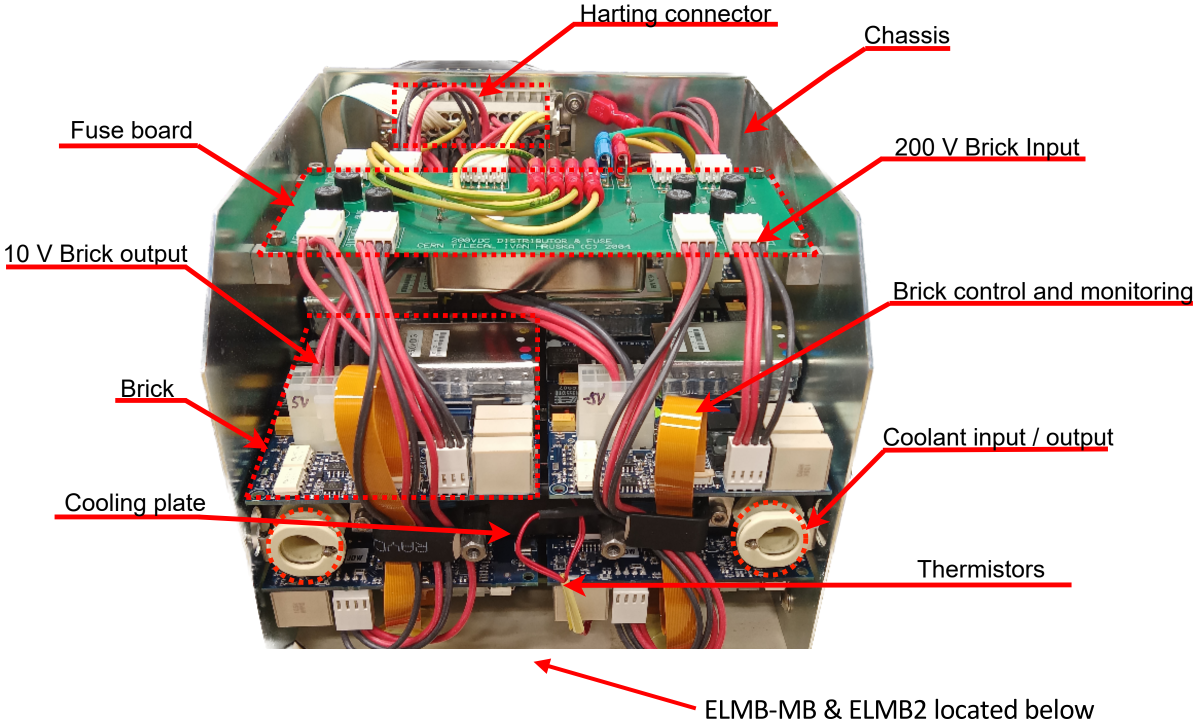


Fig. Fully populated legacy fLVPS without cover.

Embedded Local Monitoring Board (ELMB)
Embedded Local Monitoring Board Mother-Board (ELMB-MB)

Phase-II Upgrade fLVPS Brick

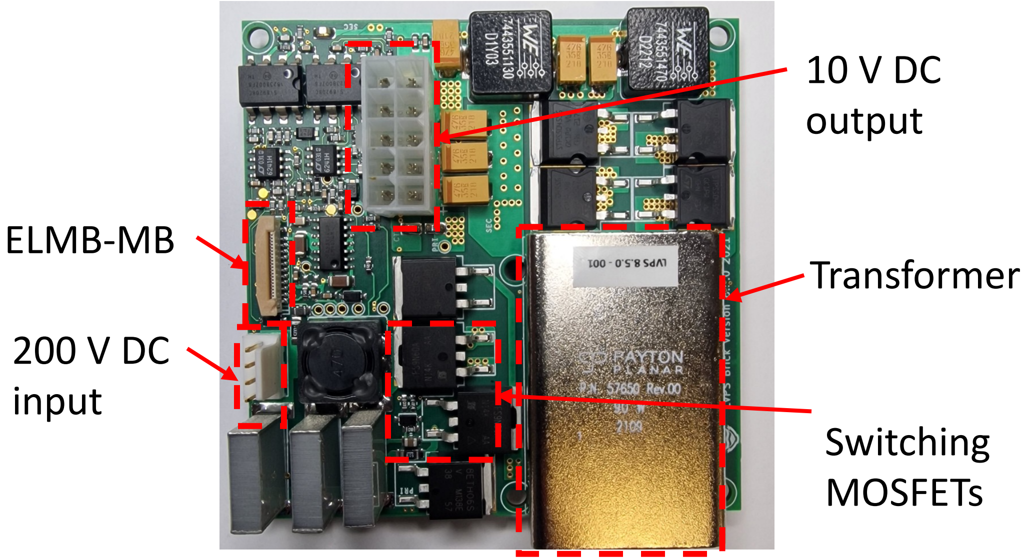


Fig. South African V8.5.0 LVPS Brick top view .

- A transformer-coupled buck converter.
- Converts bulk 200 V DC power to the 10 V DC which is then distributed to the Front-end electronics.
- Makes use of inbuilt protection circuitry – Over voltage protection, Over current protection and Over temperature protection.
- Production equally shared between USA (UTA) and SA (Wits).
- A total of 1128 LVPS Bricks to be locally produced in South Africa over the next two years (Pre- and Main-production).
- The required lifetime of a Brick within TileCal is ~ 20 years (End of Run-5).
- Current version V8.6.0

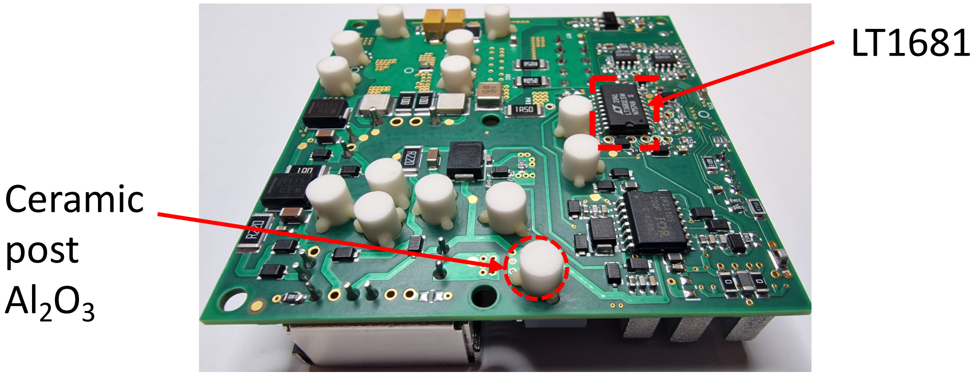


Fig. South African V8.5.0 LVPS Brick bottom view .

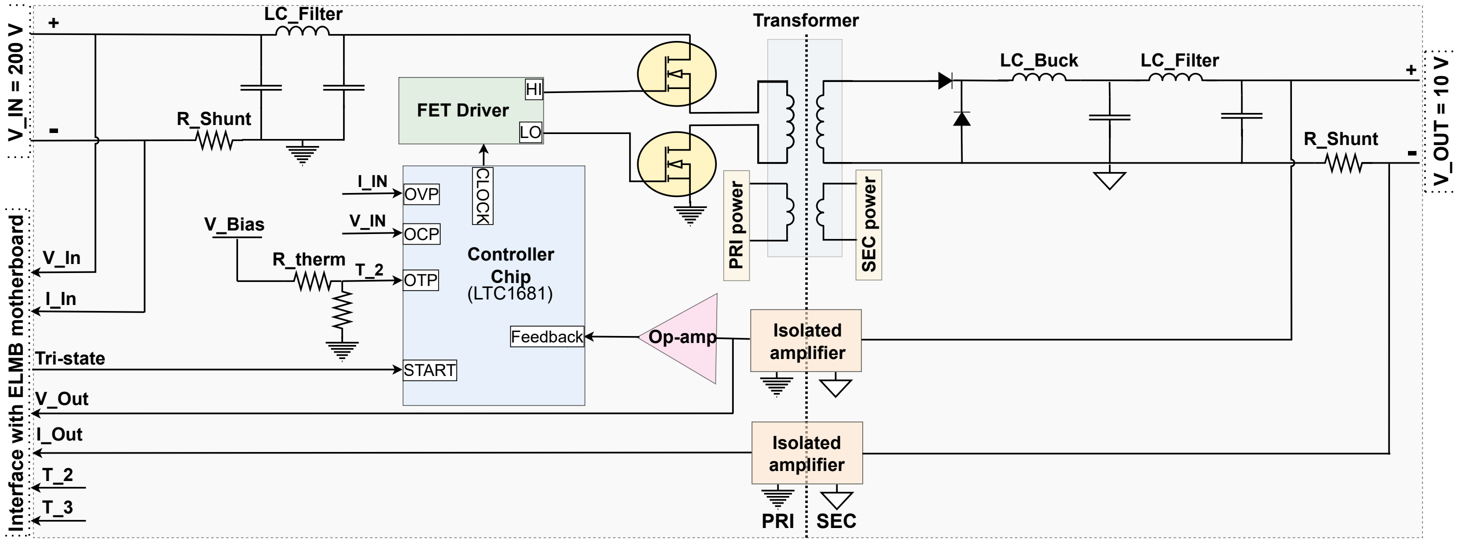
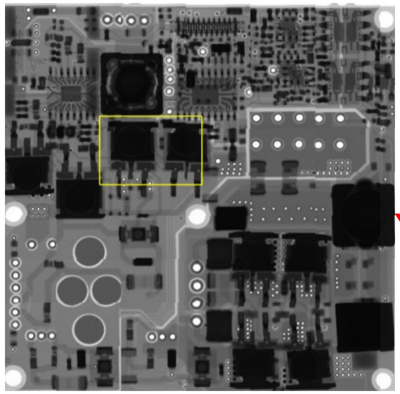


Fig. LVPS Brick functional block diagram.

fLVPS Brick Quality Assurance Testing



- Solder Voiding?

Performance metrics measured:
- Input/Output – Voltage/current
- Protection circuitry trip points (OVP, OCP)
- Tristate voltage level.

Identical to Initial Testing
- Identify performance "degradation" associated with burn-in.

- Component placement?
- Reflow sliding?

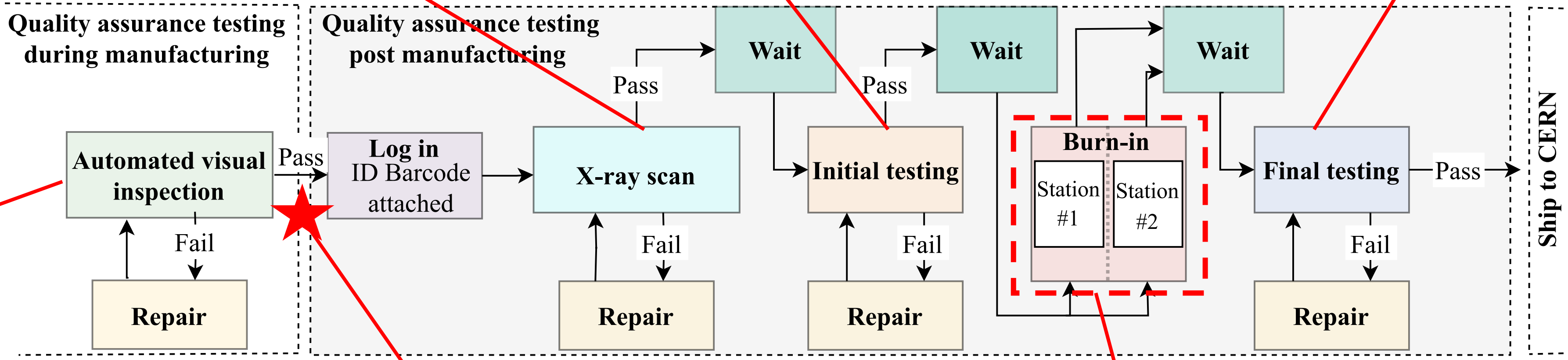
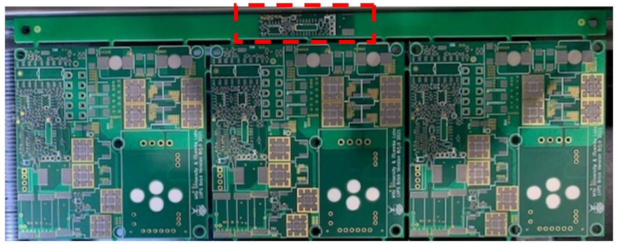


Fig.1 fLVPS Brick Quality assurance procedure.

Parallel operation due to "bottleneck"

Locally produced elements:
- ✓ Printed Circuit Boards
- ✓ Ceramic posts
- ✓ Production of final product

D-coupon testing has been newly introduced



Burn-in motivation

FE: Front-end
HASS - Highly Accelerated Stress Screening
HALT - Highly Accelerated Life Testing

- Access to the Bricks is limited to approx. once per year. => Bricks and the FE electronics powered can be offline up to a year.
- Failure rate of electronics can be represented by a generalized "Bathtub" curve.
- Burn-in testing serves to address the infant mortality region by performing accelerated ageing of the Bricks.
- System level burn-in is to be undertaken
- Burn-in is primarily focused on detecting patent defects which appear during the early life of the Bricks.
- Latent defects, that usually appear during normal operation, can be converted into patent defects via external overstress.

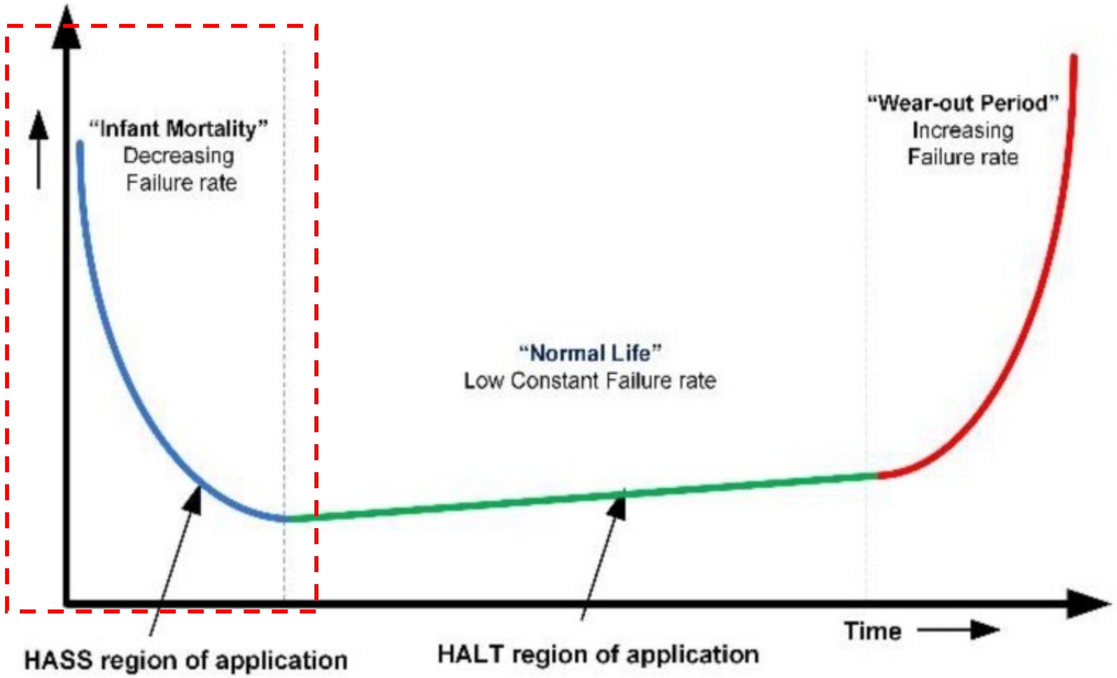


Fig. *A Bathtub curve illustrating the failure rate as a function of time for electronic products. Muhammad.N et al. doi:10.3390/mi11030272.*

Burn-in procedure

- The purpose of the Burn-in procedure is to accelerate aging of the Bricks.
- This is achieved by subjecting the Bricks to external overstress in the form of increased temperature and load.
- The Bricks operating temperature is increased by reducing the cooling capacity of the heatsinks (Cooling plates) to which they are attached.
- The Burn-in parameters are higher than nominal to ensure accelerated aging but have to remain below the limits imposed by the Bricks protection circuitry.

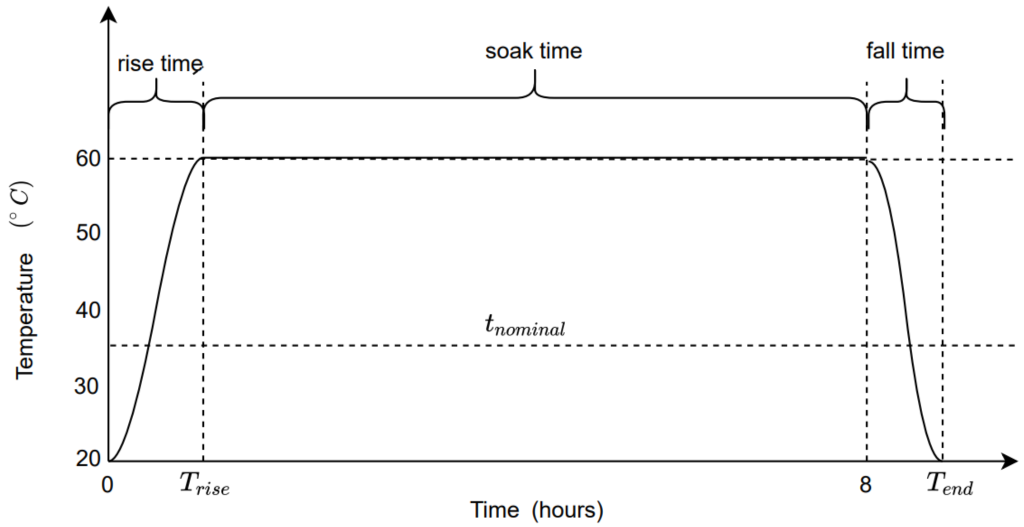


Fig. Generalized Phase-II upgrade Brick burn-in procedure thermal profile..

Parameter	Burn-in	Nominal	Protection circuitry trip points
Operating temperature	60° C	~ 35 ° C	70° C
Load	5 A	2.3 A	6.9 A
Run Time	8 hours**	-	-

Table : V8.6.0 Brick Burn-in parameters, nominal Brick operating parameters and protection circuitry trip points.

*The nominal operating temperature is heavily influenced by the primary side MOSFETS. ** The Burn-in run time is currently undergoing additional research. 8-hours is a legacy parameter.

Burn-in Test Station Overview

PC = Personal Computer
GUI = Graphical User Interface

The Test station is composed of 4 elements which work together to facilitate the Burn-in of 8 Bricks per test cycle:

- **Test bed** – Required to contain the Burn-in station electronics, provide thermal and electrical insulation.
- **Cooling system** – Provides active cooling of the Bricks as well as the Dummy-Load boards. Allows for the control of the Bricks operating temperature.
- **Hardware**– Allow for control and monitoring of the Bricks and the applied load.
- **Software** – Allows for the control of the custom electronics, the HV power supply as well as the storage and real time viewing of data.

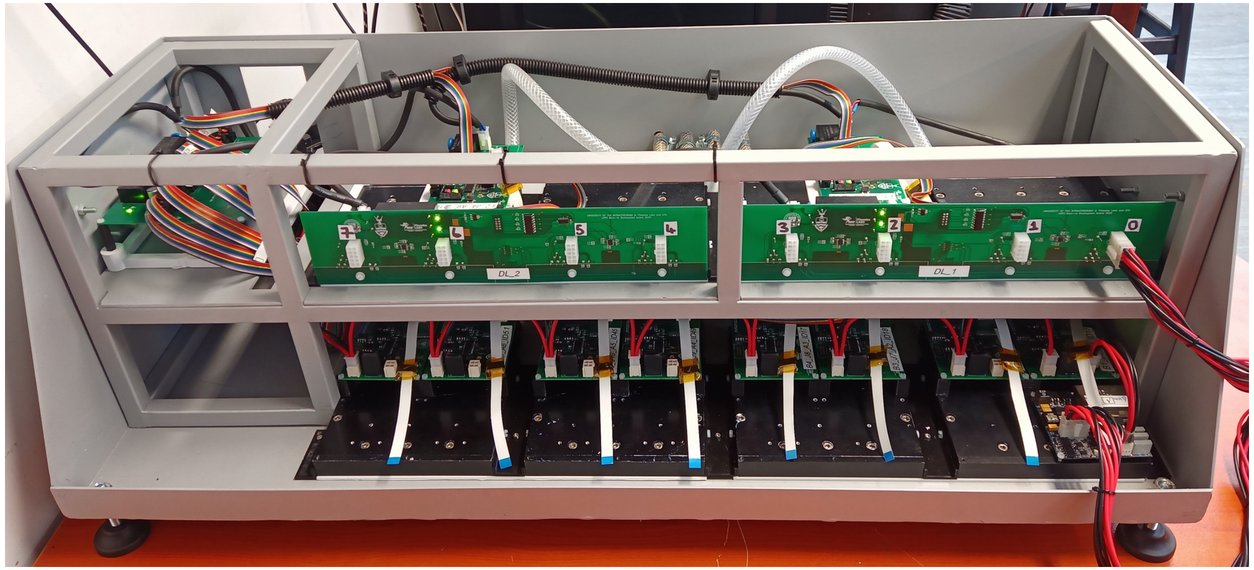


Fig.18 *Burn-in station test-bed with top and front lids removed.*

(A) Test-bed (B) PC (C) DC power supply (D) Water chiller (E) GUI

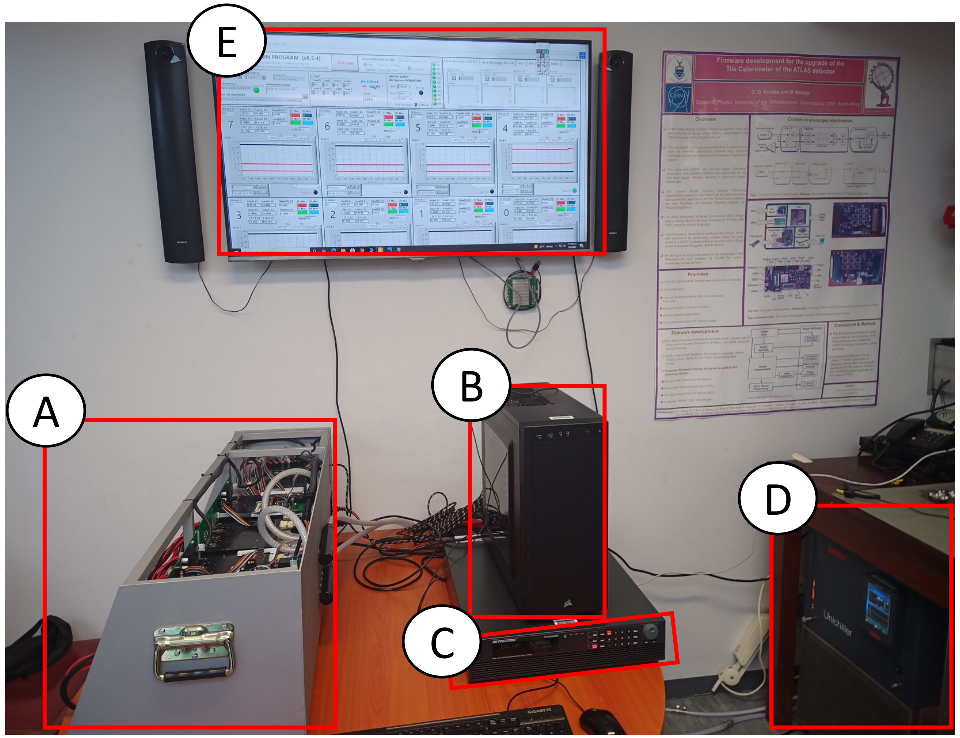


Fig. Burn-in test station.

Burn-in Test Station Hardware

BIB = Burn-in Interface Board
LIB = Load Interface Board
MB = Main Board
DLB = Dummy-Load Board
HV = High Voltage
PIC = Programmable Integrated Circuit
BLA = Burn-in Labview Application
CP = Cooling Plate
VCCS = Voltage Controlled Current Sink

The hardware modules are categorized into 4 types:

- **Main Board (MB)** x1, responsible for communicating to the BIBs and LIBs through an application-specific control and monitoring program developed in LabVIEW.
- **Brick Interface Board (BIB)** x8, interface between the MB and the eight Bricks undergoing burn-in. They digitize performance metric analog signals (such as output voltage) received from the Bricks. The BIBs are also used to switch the Bricks on/off and act as a switch for the 200 V DC input to a Brick.
- **Load Interface Board (LIB)** x2, interface between the MB and DL boards. As with the BIBs they digitize performance measurements obtained from the DLs (voltage and current of the brick output measured at the DL). The LIBs also control the load current of a Brick via VCCS located on the DLs
- **Dummy Load Board (DLB)** x2, make use of 4 VCCS that use high precision op-amps and N-channel MOSFETs which are affixed to the CPs to dissipate the heat generated

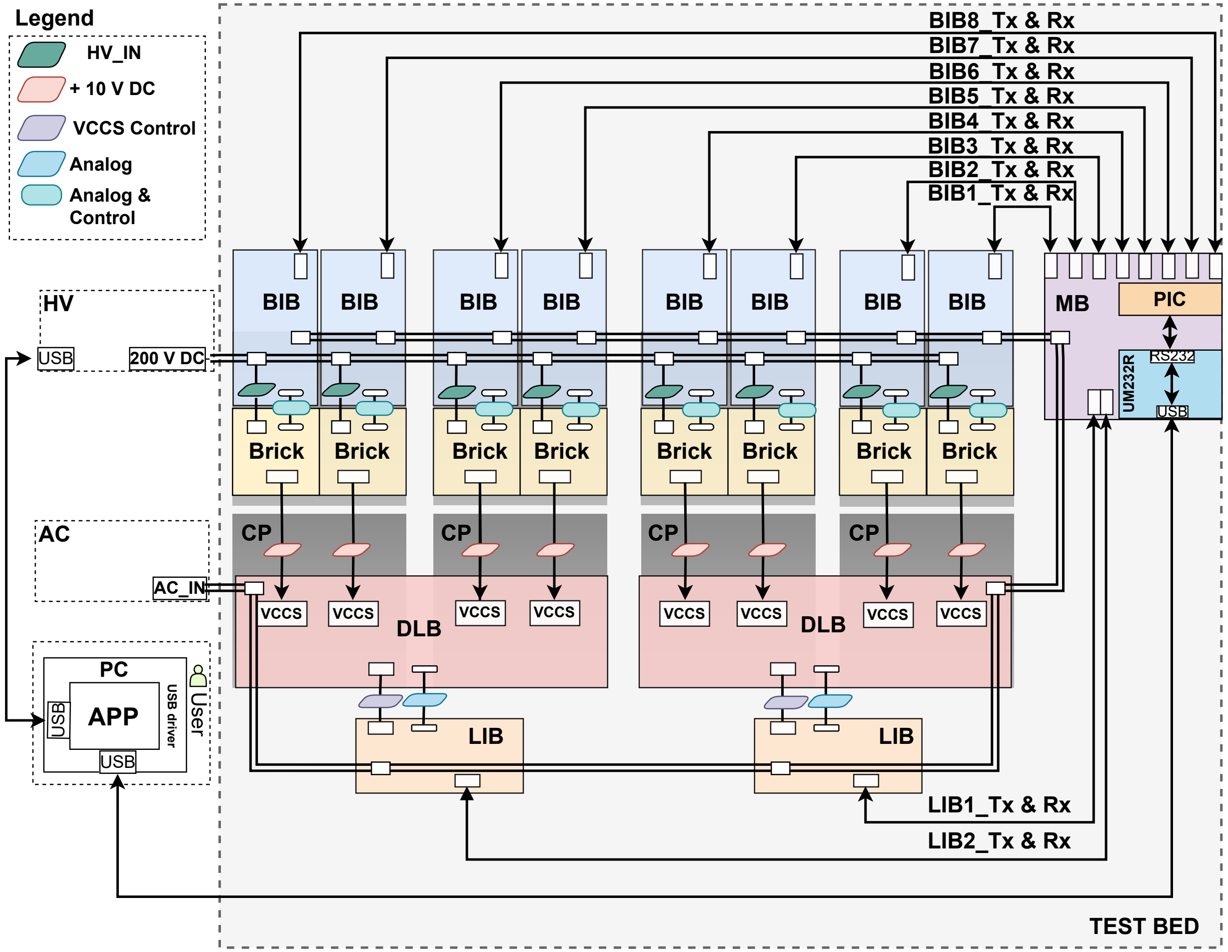


Fig. *Block diagram illustrating the burn-in station hardware.*

Burn-in Test Station Software

BIB = Burn-in Interface Board
LIB = Load Interface Board
MB = Main Board
DL = Dummy-Load
HV = High Voltage
PIC = Programmable Integrated Circuit
BLA = Burn-in Labview Application

- The Burn-in LabVIEW Application (BLA) and PIC firmware were originally developed by Argonne National Laboratory (ANL) in 2006 for the V6 Brick.

Software required for the operation of a Burn-in station can be divided into three categories:

- **BLA** provides control and monitoring of the Burn-in station and communicates via a PC over USB to the MB and PVS60085MR HV power supply. A PC runs the BLA responsible for Brick identification, Brick selection, Brick control (starting, stopping and load current), Brick and load performance measurements, HV control and monitoring, Brick trip detection and automatic restart, Burn-in time management and data logging.
- **PIC firmware** The MB embeds PIC firmware responsible for addressing and communicating from the BLA to the Interface boards of the Burn-in station.
- **Power supply instrumentation driver -** software routines that control the programmable instrument.

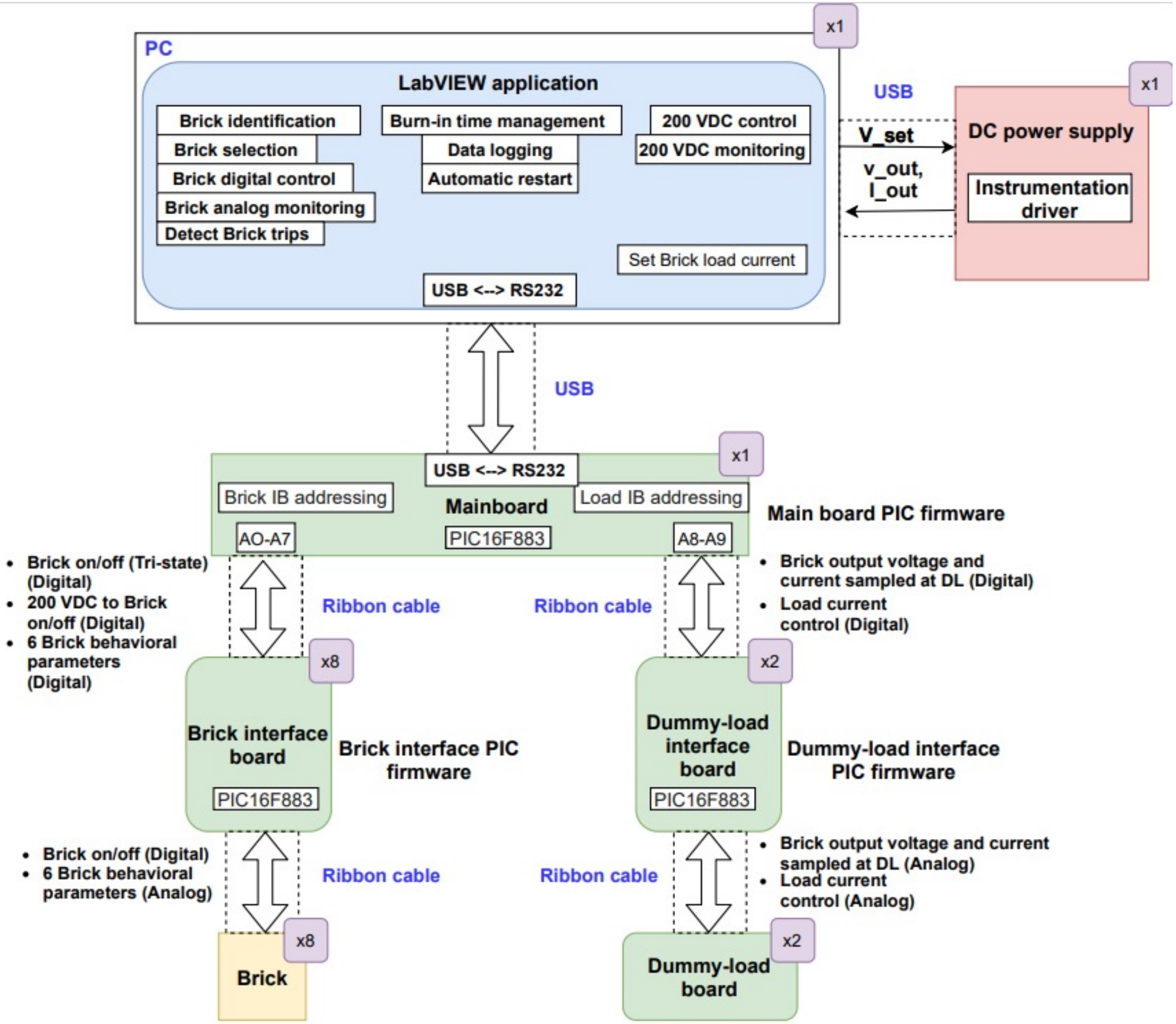


Fig. A simplified block diagram of the Burn-in station communication system..

Outlook – Towards Pre-production

Burn-in station design finalized

- Hardware and software are ready.

“Burning in” the Burn-in station.

- Commissioning of the first test station has been completed.
- Prolonged testing has highlighted that the VCCS MOSFETs were getting far too hot. Numerous protection Thermostat trips and shorted MOSFETs.
- A single cooling system for both the Bricks and Dummy-loads means that additional radiative cooling is the only option (Heatsink + Fan).

Fig. V8.4.2 Brick undergoing burn-in.

Replication

- The second Burn-in station is under construction. To be completed before main-production.

Pre-production

- Anticipated to commence in the coming months pending V8.6.0 approval
  - Mixed beam (CHARM) certification of active components.
- 104 units to be produced in SA. QA testing to take approx. 2 weeks.

Main-production

- Anticipated to commence in early 2024.

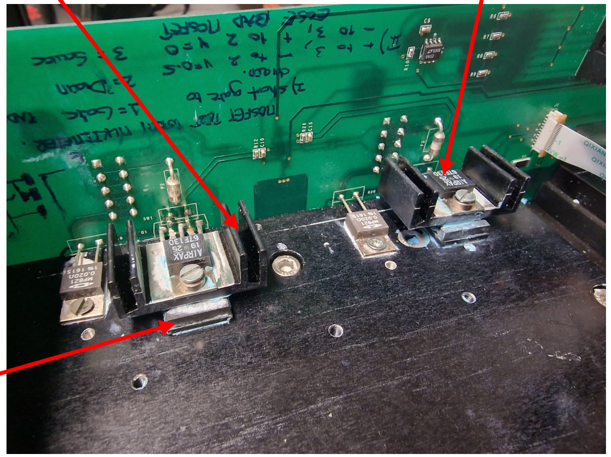
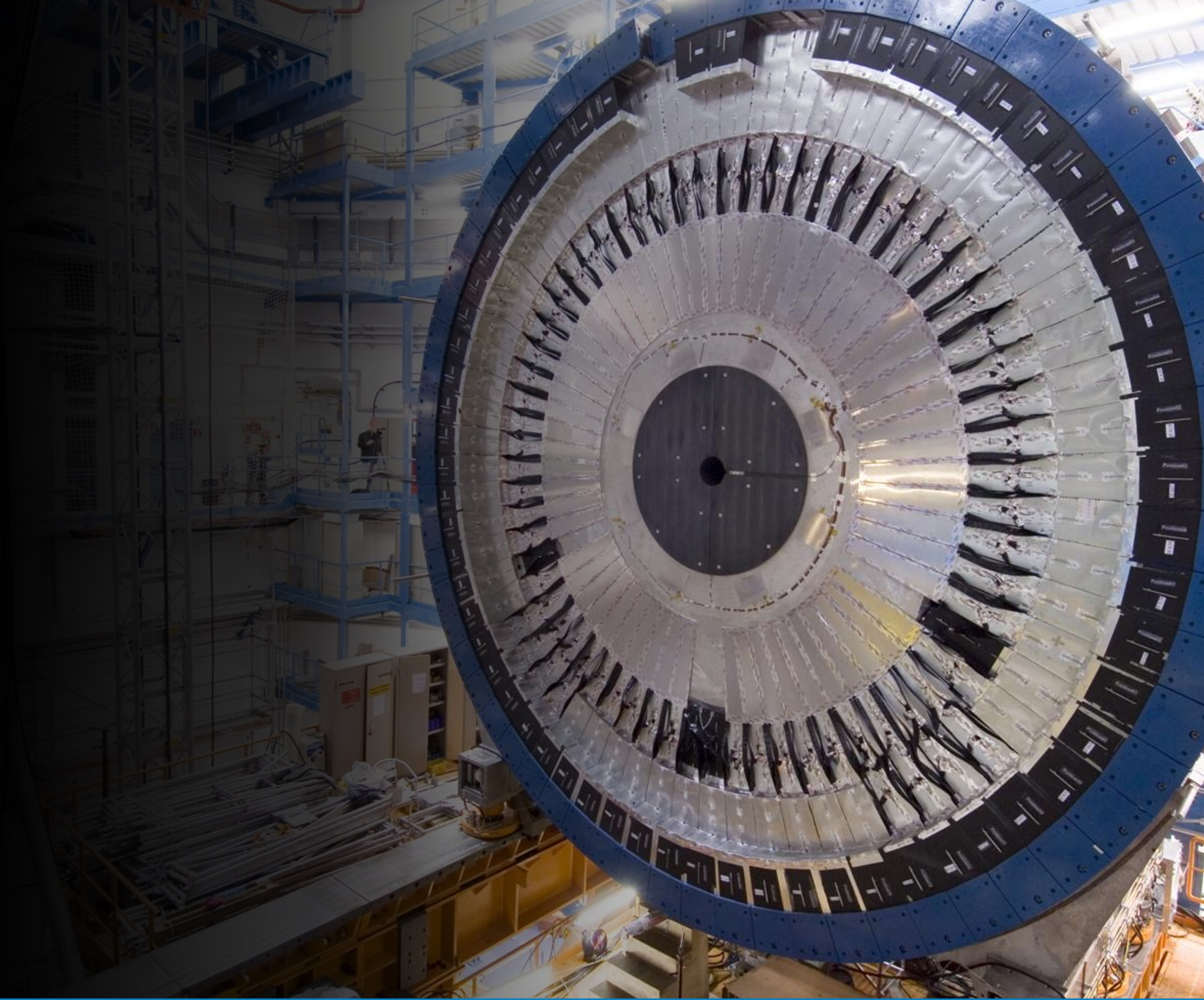


Fig. Dummy-load VCCS connected to cooling plate.

Questions?



The HL-LHC Timeline

The ATLAS detector*

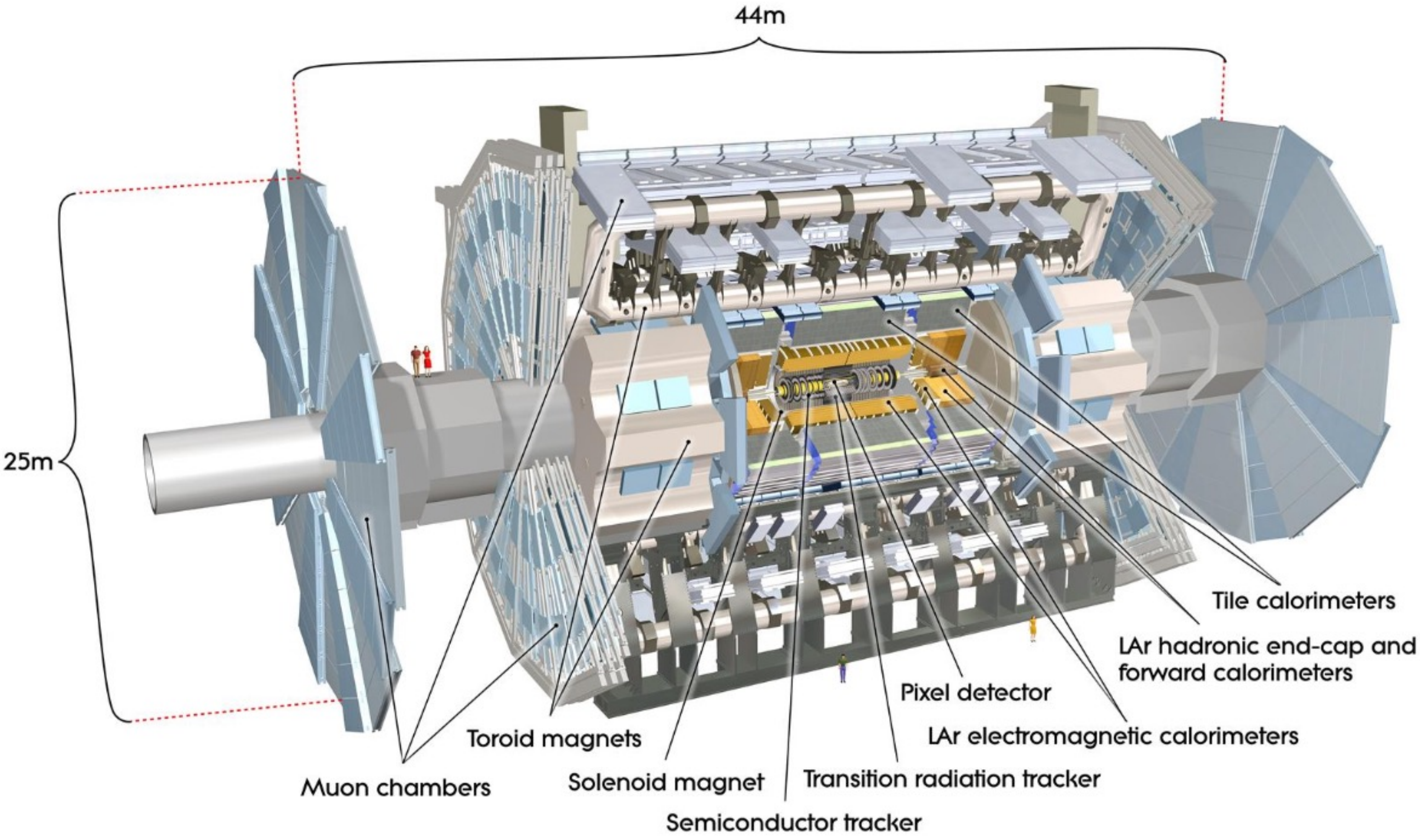


Fig.15 The ATLAS detector

* Pre-LS3

Legacy Low-Voltage System

- A **2-stage system** in which Bulk 200 VDC power is converted to the voltages required by the FE electronics by different types of Brick.
- **Provides ON/OFF control** (Via Aux-boards) of the bricks in two groups which start successively.

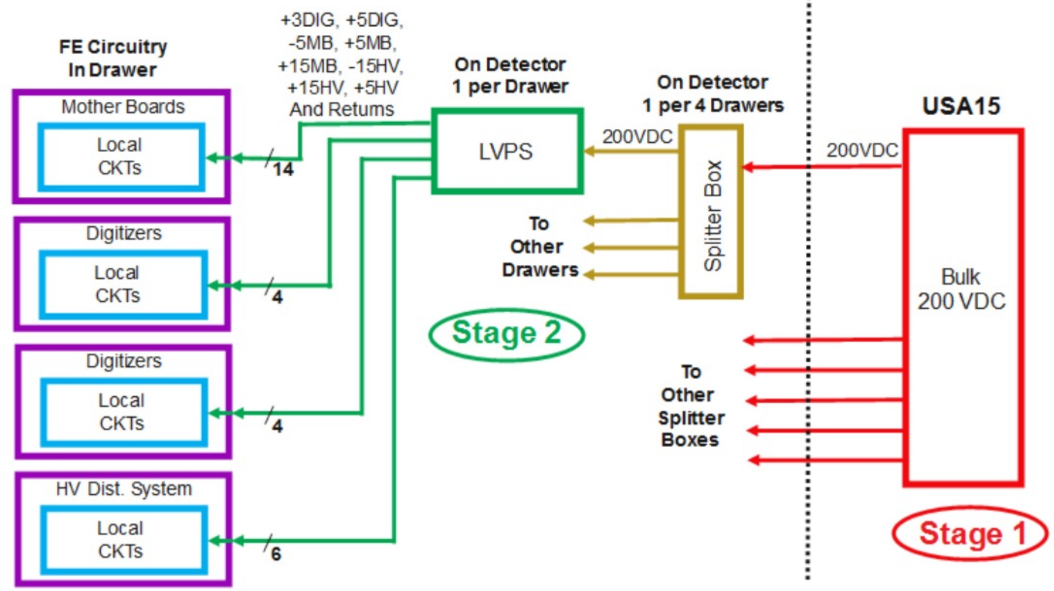


Fig. Block diagram of the legacy 2-stage low-voltage system.

Phase-II Upgrade

- **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 brick with a standardized 10V output;
- **Tri-state functionality** is being introduced which allows for individual Bricks startup/shutdown. This functionality is so named due to the Aux-boards ability to send 3 different state signals to an LVPS Brick;

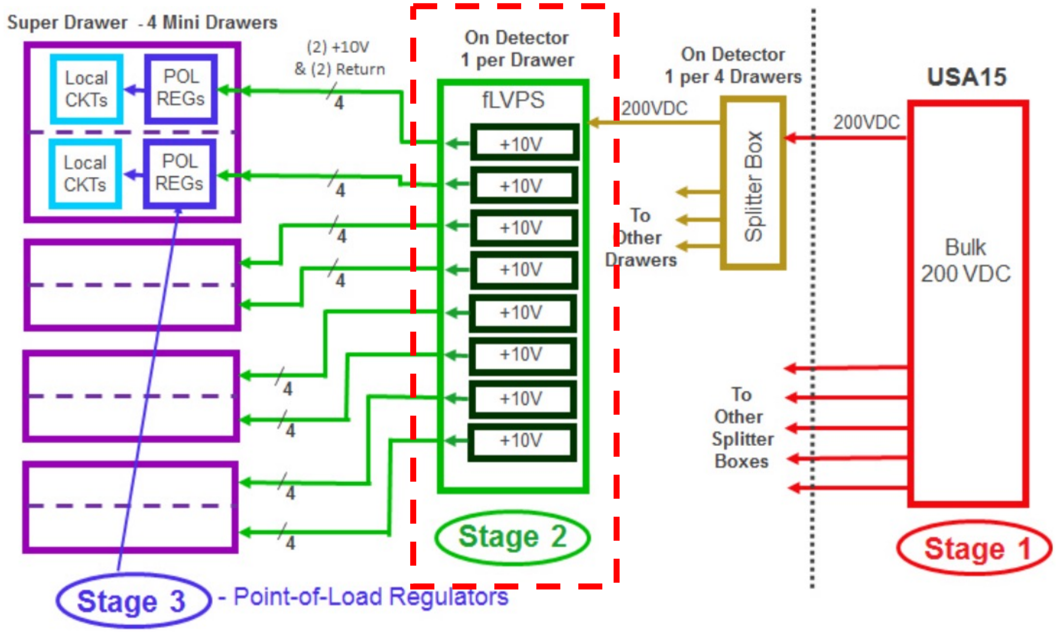
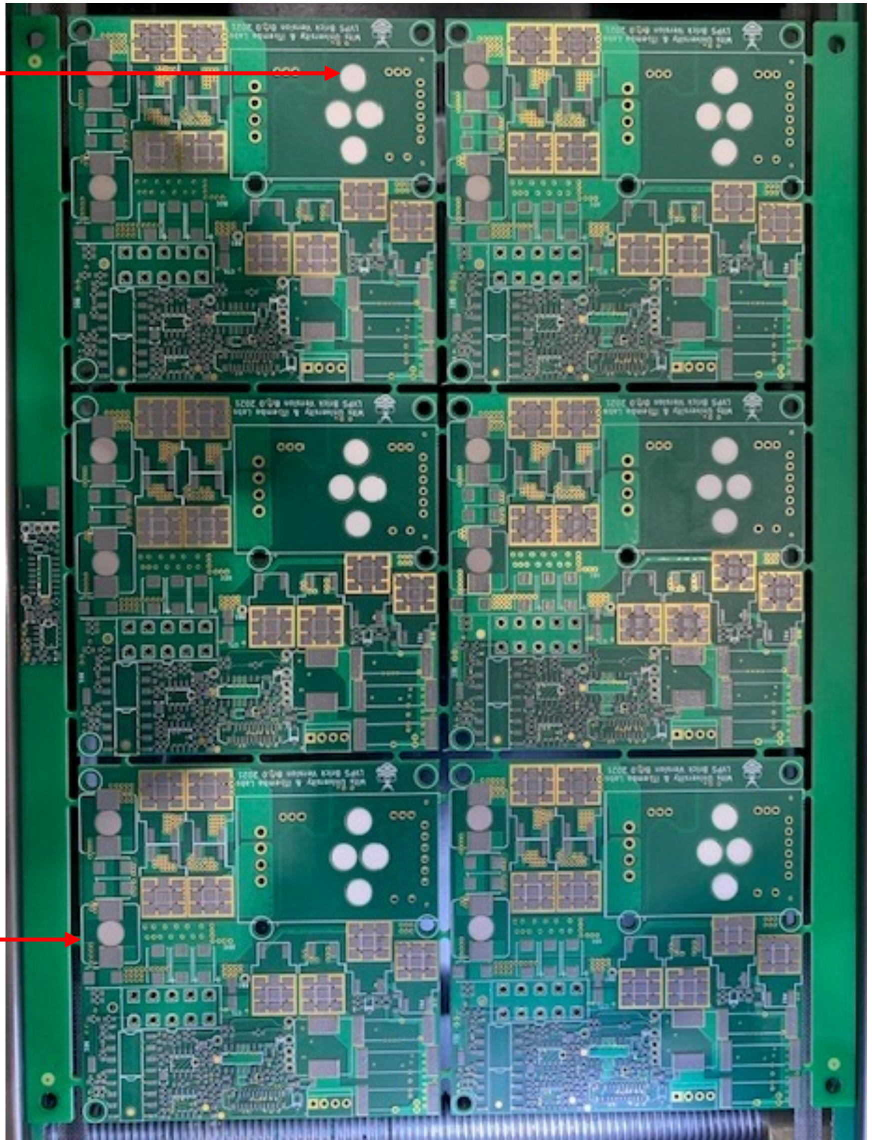


Fig. Block diagram of the Phase-II upgrade 3-stage low-voltage system.

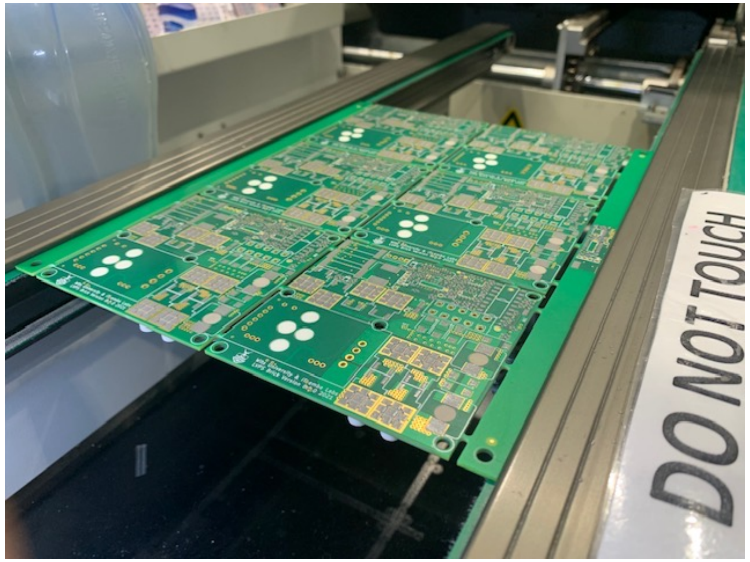
Brick Panel Population

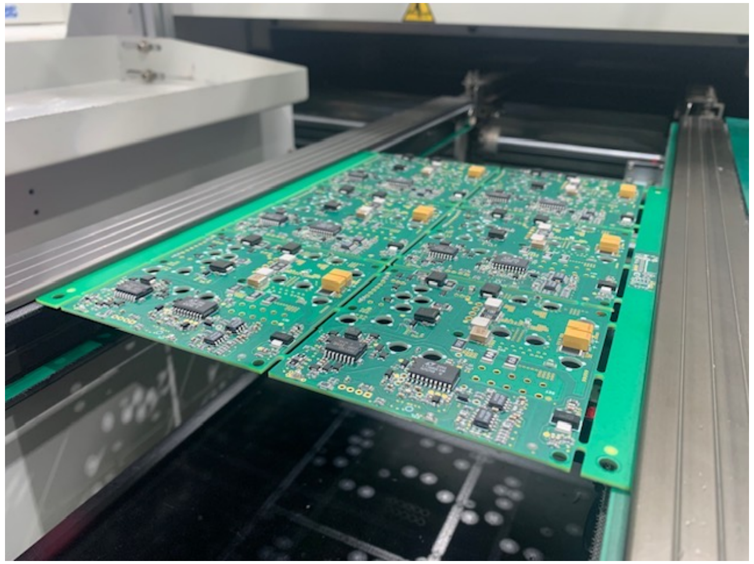
Non-metalized



Metalized

Silver Palladium Conductor





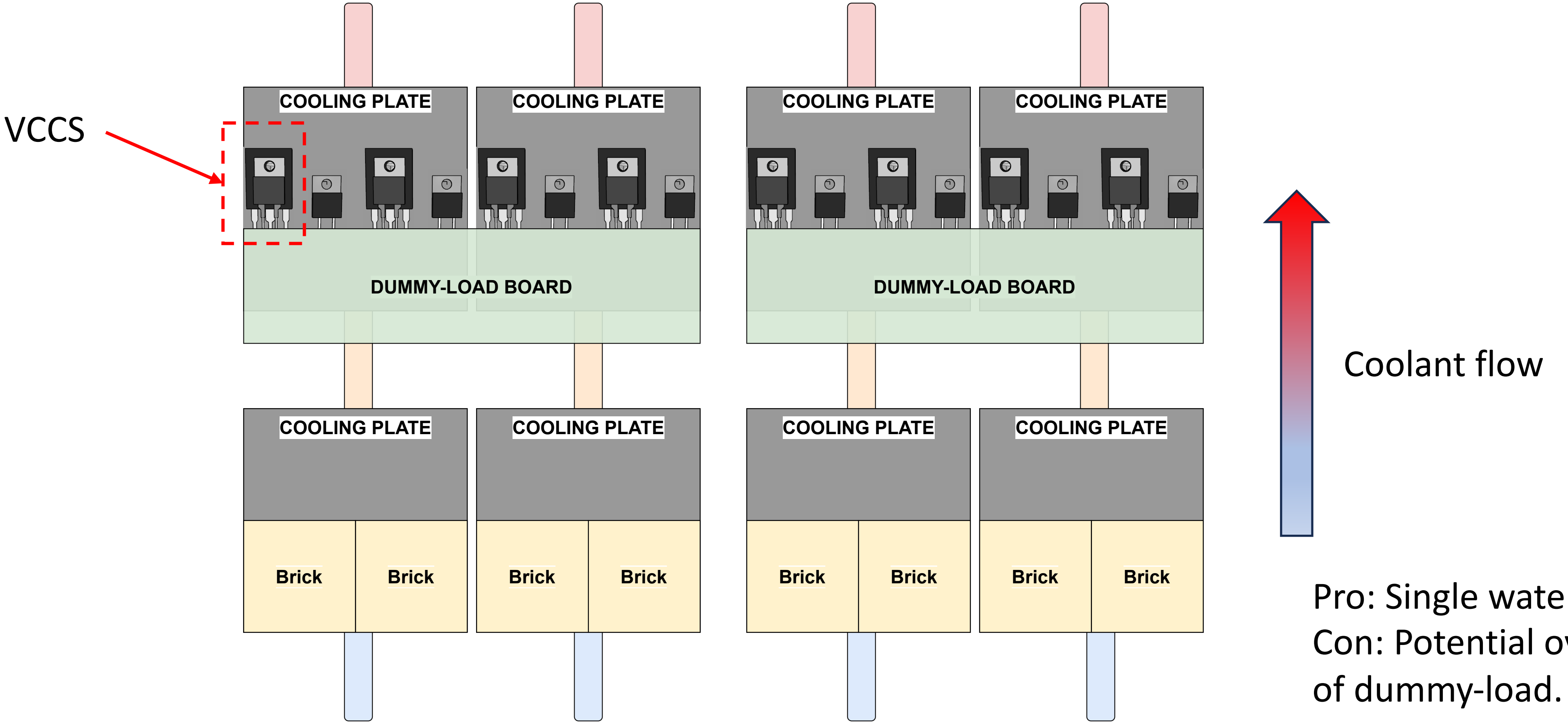
Brick Tri-state Signal

START = 15 or 17 V DC at the receiving end (brick), I =150 mA, duration 1 second. This signal initially powers the primary side of a brick. After starting, the brick primary side powers itself.

RUN = High impedance: only if the brick has already been started, the circuitry of the brick imposes a voltage of 6.0±0.2 V on this Tri-State line, when it is in high impedance mode, which keeps the voltage regulator LM9074 enabled. However, if the brick is off, the high impedance state does not turn it on, as there is no voltage on the brick. So once a brick is turned off (for example due to a trip), only a START voltage can turn it back-on.

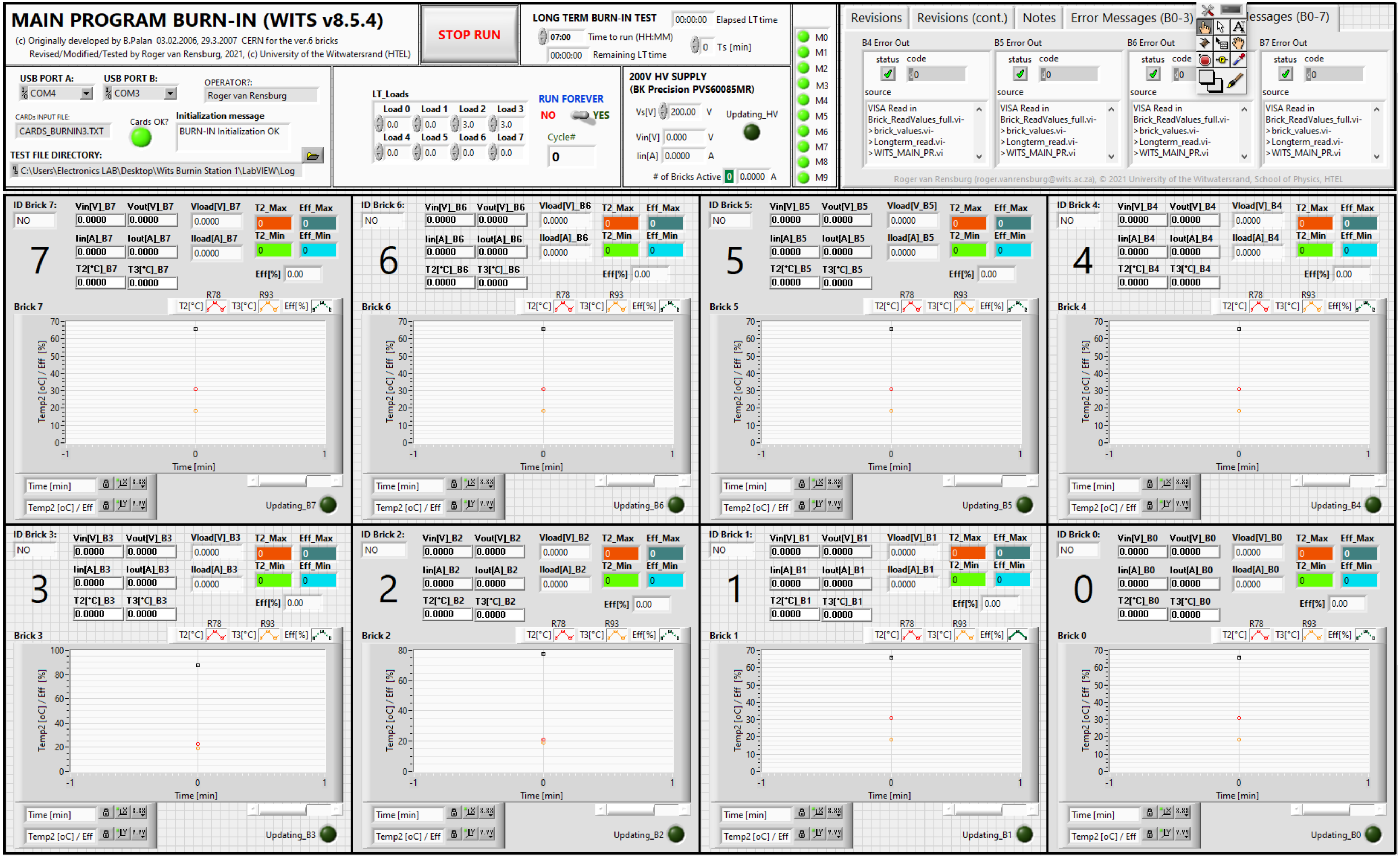
DISABLE < 2 V DC at the receiving end (brick), I=0 A. Line is simply shorted to ground on the AuxBoard. This signal state disables the LM9074 regulator on the brick, which will turn the brick off.

Burn-in station temperature control system



Pro: Single water "chiller"
Con: Potential overheating of dummy-load.

Burn-in station GUI



TileCal Phase-II Upgrade Simplified Block Diagram