A Burn-in test station for the ATLAS Phase-II Tile-calorimeter low-voltage power supply transformer-coupled buck converters

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The ATLAS Tile-Calorimeter

- The 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.
- A Low-Voltage Power Supply (LVPS), of which there is one per TileCal module, steps down 200 V DC, received from off-detector high-voltage supplies, to the 10 V DC required by the front-end electronics.
- The LVPS's location can be seen in Fig.1 where they are housed within shielding (blue boxes) attached to the outer radii of the Tilecal modules.

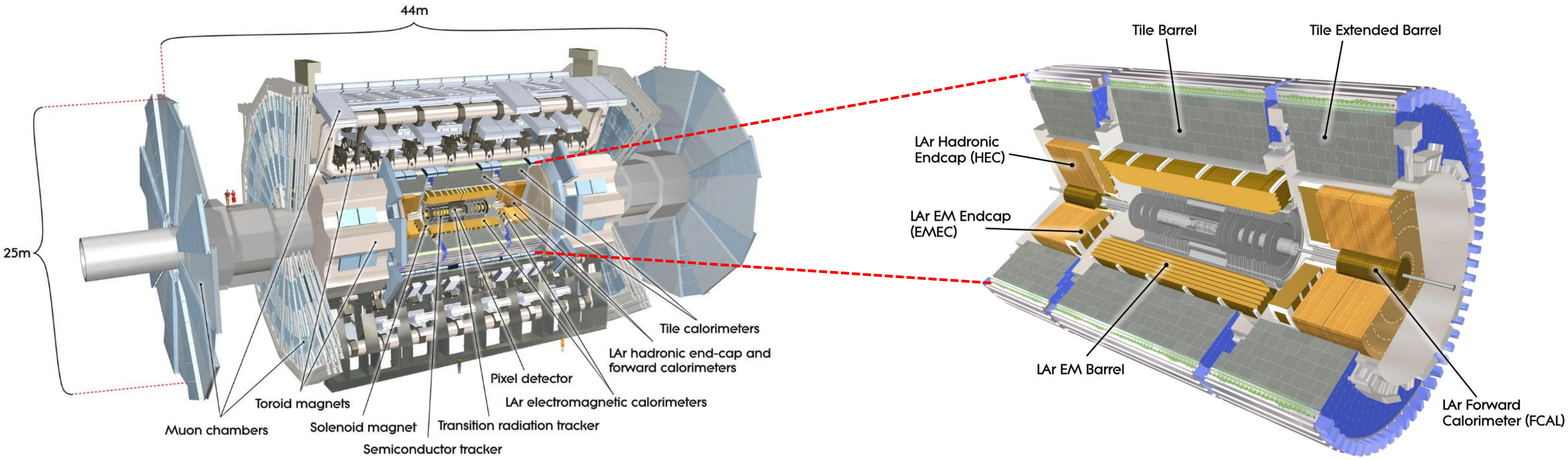


Fig.1 The ATLAS detector (Left). The ATLAS inner Barrel (Right) *-J. Pequenao, Computer Generated image of the ATLAS calorimeter,(2008), https: // cds. cern. ch/ record/ 1095927*

Phase-II Upgrade LVPS Brick

FET – Field Effect Transistor
OVP – Over Voltage Protection
OCP – Over Current Protection
OTP – Over Temperature Protection
SD – Super Drawer

- In the year 2029 the start of the operation of the High-luminosity Large Hadron Collider(HL-LHC) is planned .
- The resulting HL-LHC environment has necessitated the development of new Low-Voltage Power Distribution system amongst (See reference slides for details) numerous other upgrades in order to ensure the continued peak performance of TileCal.

- See link for summary of the entire Phase-II upgrade: Link: Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC:

- LVPS Function: Provide low-voltage power to the front-end electronics of the SDs.
- An LVPS consists of an Embedded Local Monitoring Board (ELMB), a Fuse board, a water-cooled heatsink, an internal cable set, and eight transformer-coupled buck converters (Bricks).
- Tilecal contains 2048 LVPS Bricks (8 per SD).
- The Phase-II upgrade Bricks are required to operate up until the end of RUN 5 (see slide 7).

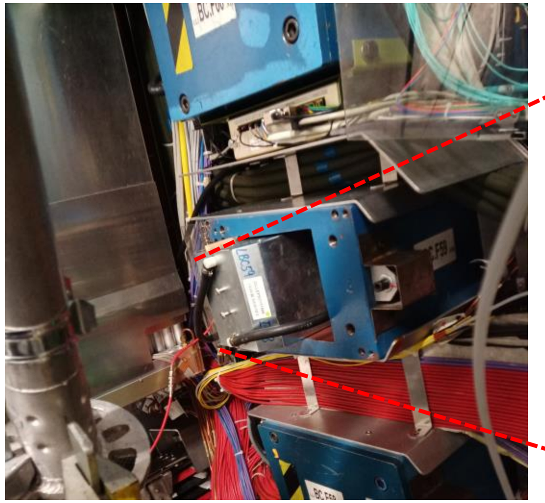


Fig.2 *An LVPS inside TileCal.*

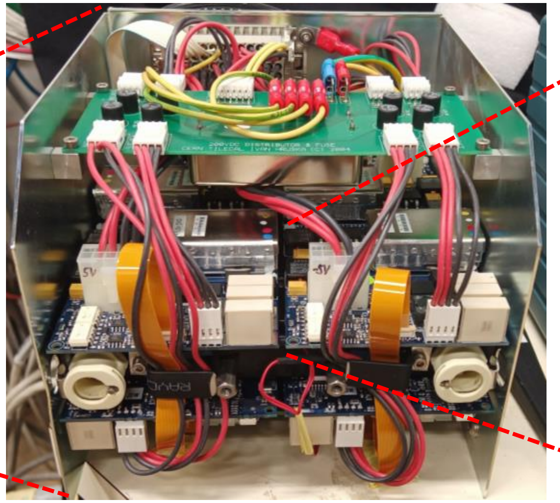


Fig.3 *Inside an LVPS.*

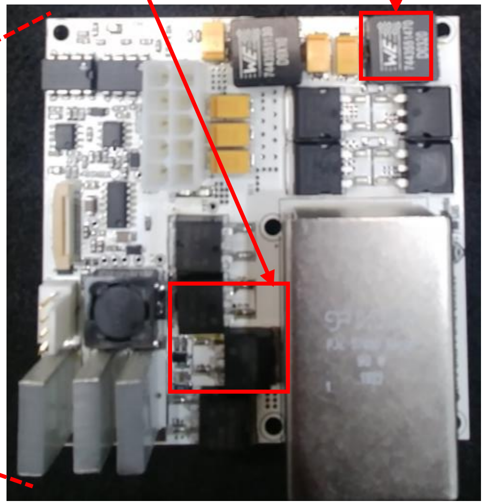


Fig.4 *High efficiency LVPS Brick top view .*

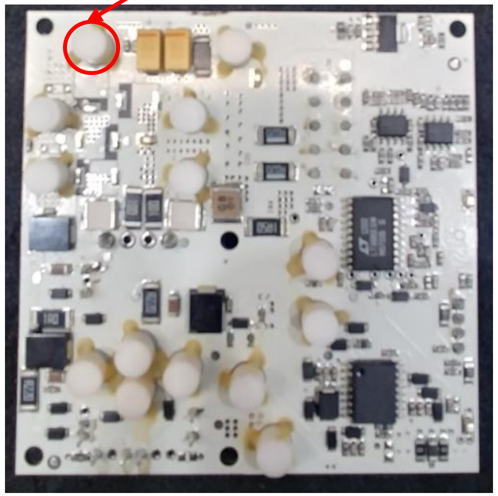


Fig.5 *High efficiency LVPS Brick bottom view .*

Phase-II Upgrade LVPS Brick

FET – Field Effect Transistor
OVP – Over Voltage Protection
OCP – Over Current Protection
OTP – Over Temperature Protection

- The Bricks transform bulk 200 V DC power to the 10 V DC required by the on-detector electronics.
- The Bricks monitor their input and output voltages, currents as well as two temperatures T2 and T3.
- A Tristate signal input is used to switch an individual Brick on/off.
- The Bricks make use of in-built protection circuitry.
- The Bricks are iterative in design.
- The TileCal Phase-II upgrade requires the replacement of 256 LVPSs. This corresponds to 2048 Bricks (Plus approx. 10% spares).
- The Brick Phase-II upgrade addresses radiation hardness requirements, new LV-distribution topology, efficiency, thermal and reliability issues.
- The production is equally divided between WITS and UTA and will take place over the next three years. Quality assurance testing (see Fig.7), of which Burn-in testing forms a part, is to be undertaken as part of the manufacturing process.

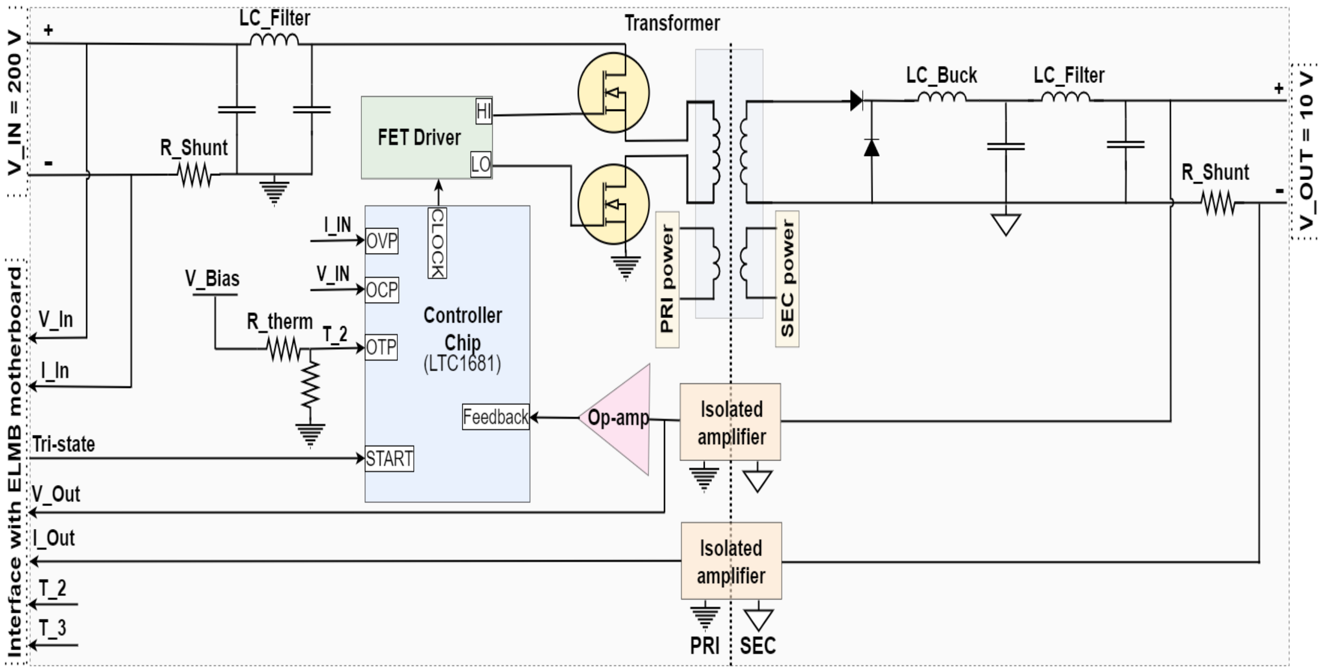


Fig.6 *A simplified block diagram of a Phase-II upgrade Brick.*

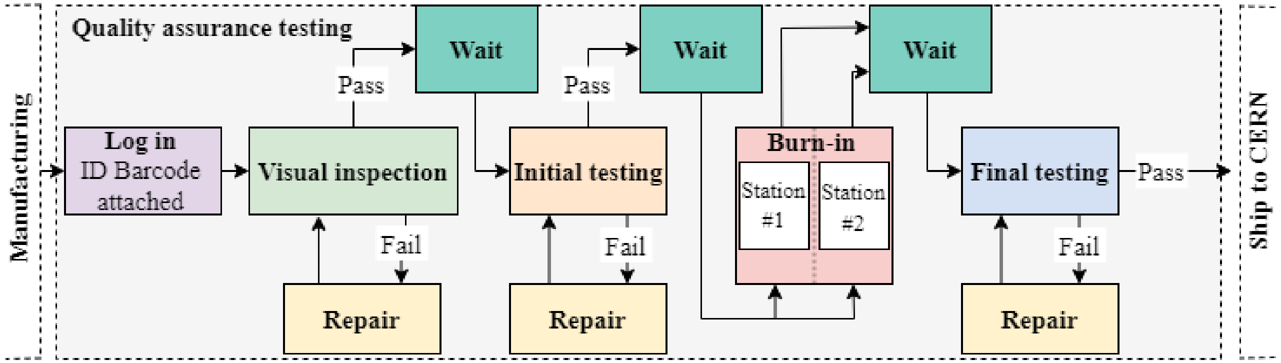


Fig.7 *Quality assurance testing of an LVPS Brick.*

Burn-in motivation

- Access to the Bricks is limited to approximately once per year. Therefore, any Bricks which fail will result in a portion of a module being offline for a commensurate time emphasizing the importance of the Brick reliability.
- To maximize reliability, we are required to minimize their failure rate. The failure rate of electronics can be represented by a "Bathtub" curve (Fig.8).
- Observe the undesirable failure rate within the infant mortality region. Burn-in testing serves to address this by performing accelerated ageing of the Bricks.
- Accelerated aging causes Bricks that would fail during their early lifetime to fail immediately thereby effectively screening out the infant mortality failures.

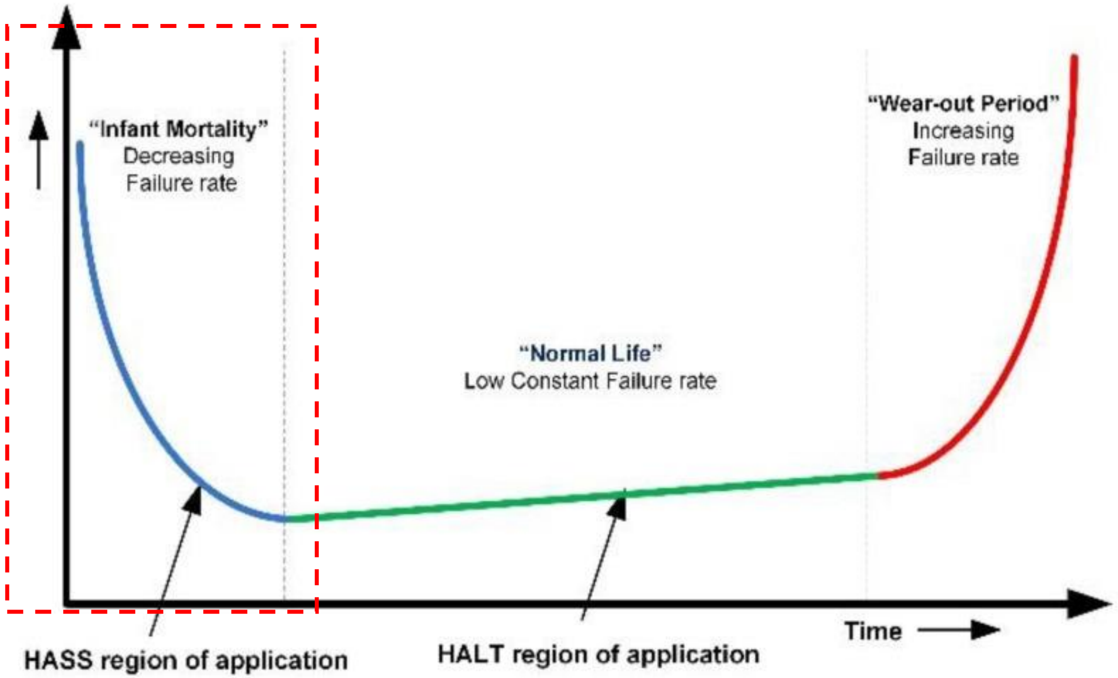


Fig.8 *A Bathtub curve illustrating the failure rate as a function of time for electronic products. Muhammad.N et al. doi:10.3390/mi11030272.*

Burn-in procedure

- The purpose of the Burn-in procedure is to accelerate aging of the Bricks. This is achieved by operating the Brick within a sub-optimal environment (increased temperature and load) thereby stimulating similar failure mechanisms which appear during normal operation.
- 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.

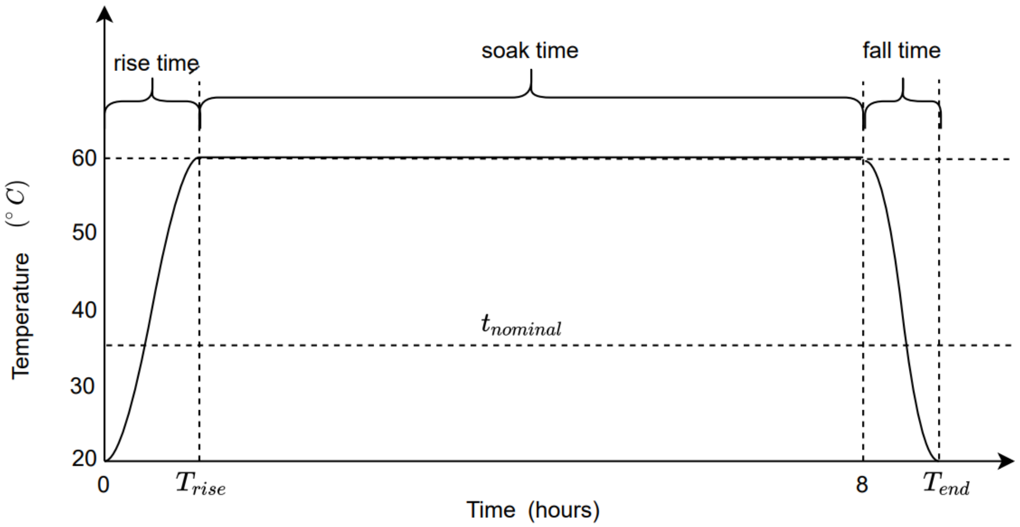


Fig.9 Generalized Phase-II upgrade Brick burn-in procedure thermal profile..

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

Table : V8.5.0 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

- As depicted in Fig.10, the Burn-in station hardware is composed of a Personal Computer (PC), a 200 VDC power supply, various custom Printed Circuit Boards (PCBs) designs, electronic components, connectors, wiring, Cooling Plates (CP), a water-chiller, and a mechanical chassis known as the test-bed. (See reference slides for software overview)

The PCBs are subdivided into four 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 Voltage-Controlled Current Sink (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

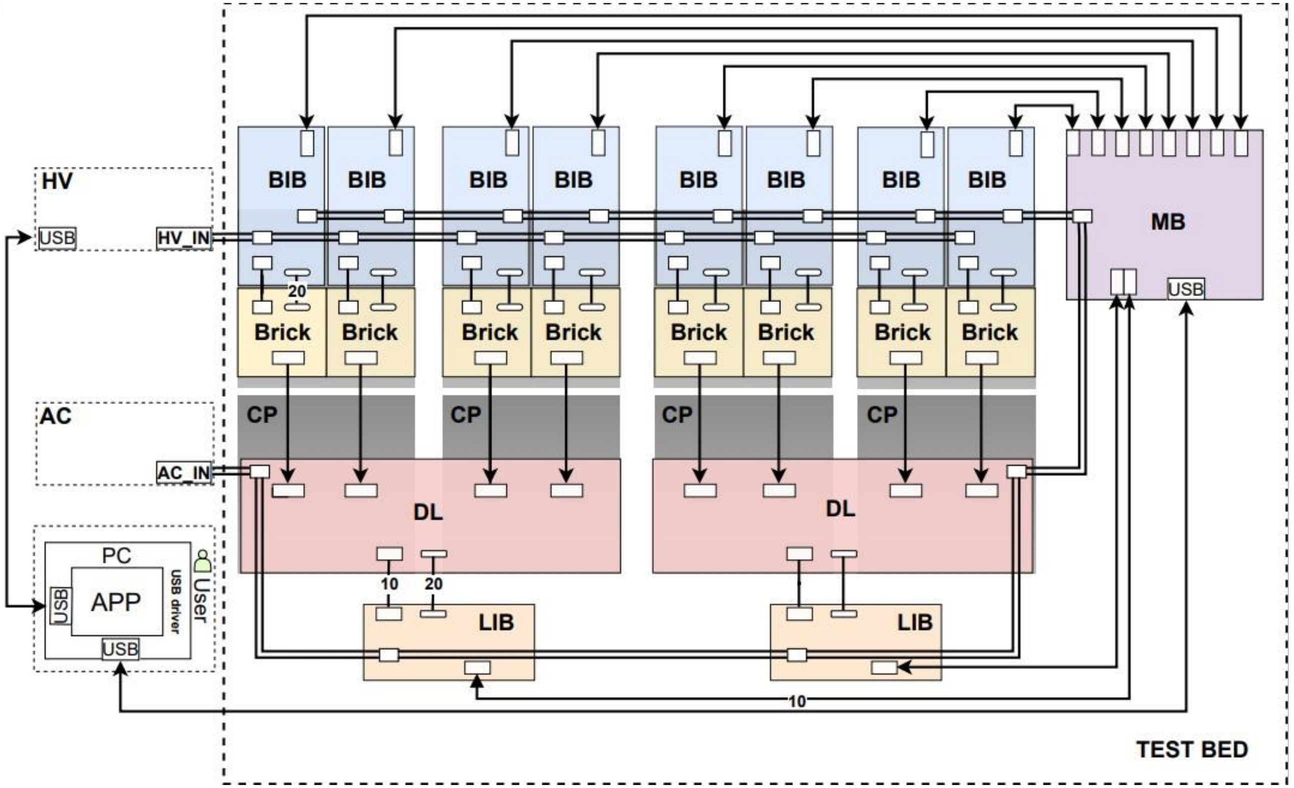


Fig.10 *Block diagram illustrating the burn-in station. Adapted from diagram by S. Moeyedi*

Preliminary Burn-in results

Water chiller set to 18 °C
Load set to 5 A
V_In = 200 V
V_Out – 11 V

- The Burn-in station is in a mature stage.
- *Preliminary hardware and software testing has commenced with favorable results observed*.
- The fully operational burn-in station can be observed in Fig.11. Note that hotspot in the righthand corner which is due to the Dummy-load MOSFETs converting the electrical energy received from the Brick into thermal energy which is to be removed.
- As can be seen in Fig. 12 the burn-in temperature parameter is being met with the hot spot being measured resulting from the primary-side MOSFETs. It is worth noting that the thermistor (with associated temperature T2) utilized for the on-Brick measurements is located adjacent to these MOSFETS and is utilized in the Bricks Over Temperature Protection (OTP) circuitry.
- The T2 temperature monitored during the Burn-in procedure is illustrated in Fig.13.
- The Burn-in temperature is stable with a mean value of 60.69°C and standard deviation of σ = 0.19°C.

Fig.11 *Thermal image of a Burn-in station undertaking burn-in of a Brick*

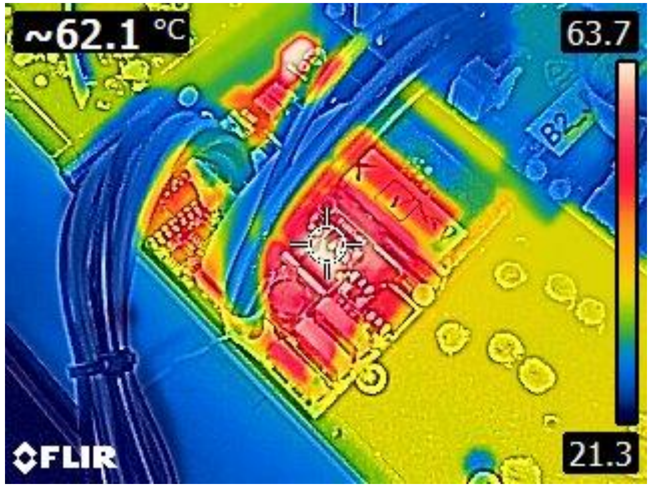


Fig.12 *Thermal image of a Brick undergoing burn-in where the target is centered on the primary side MOSFETs.*

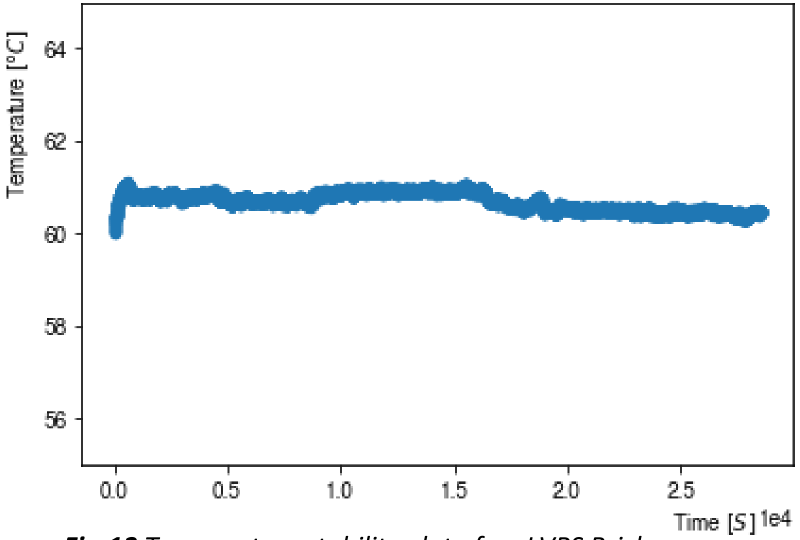
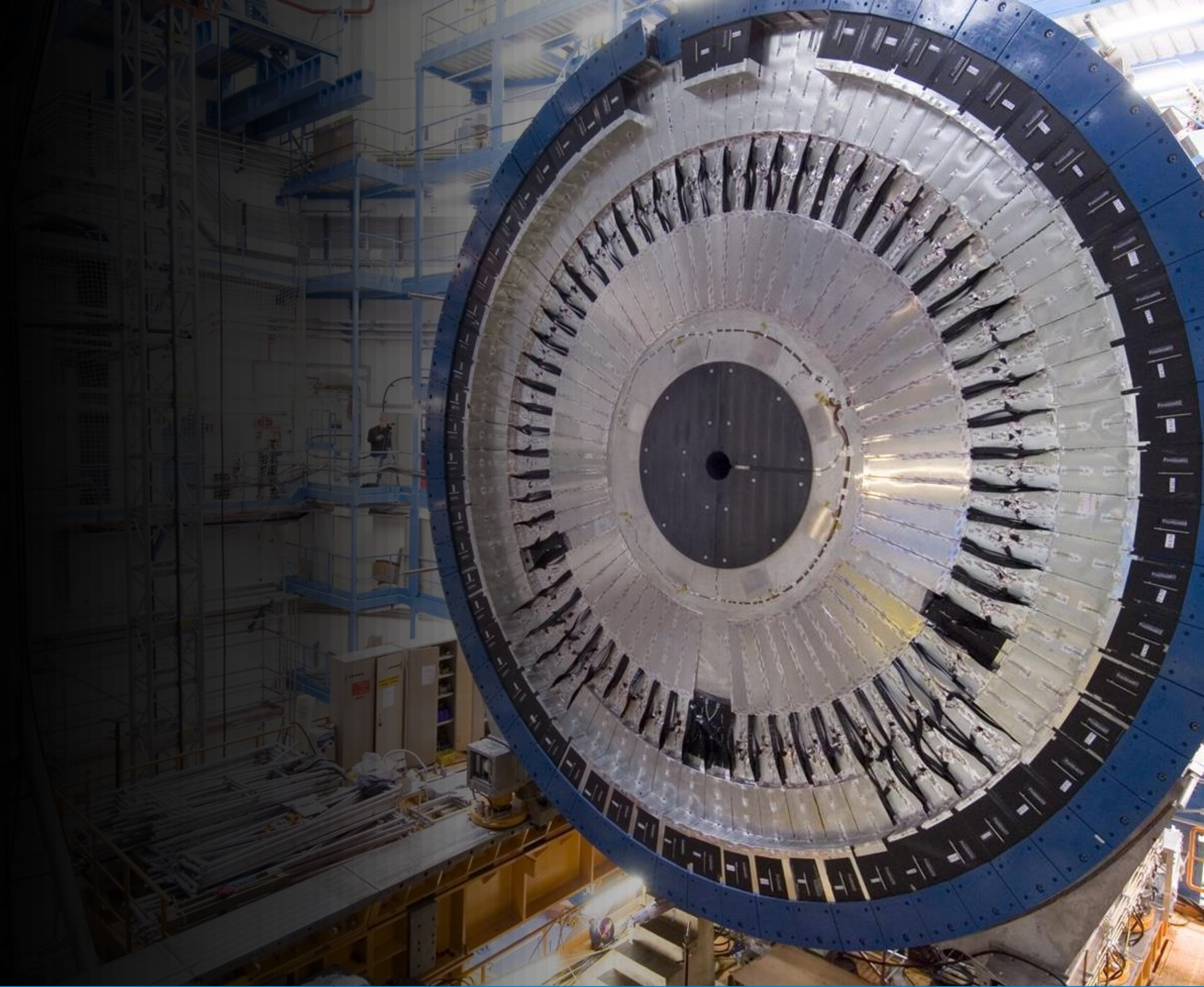


Fig.13 *Temperature stability plot of an LVPS Brick undergoing burn-in testing.*

Reference slides



The ATLAS detector

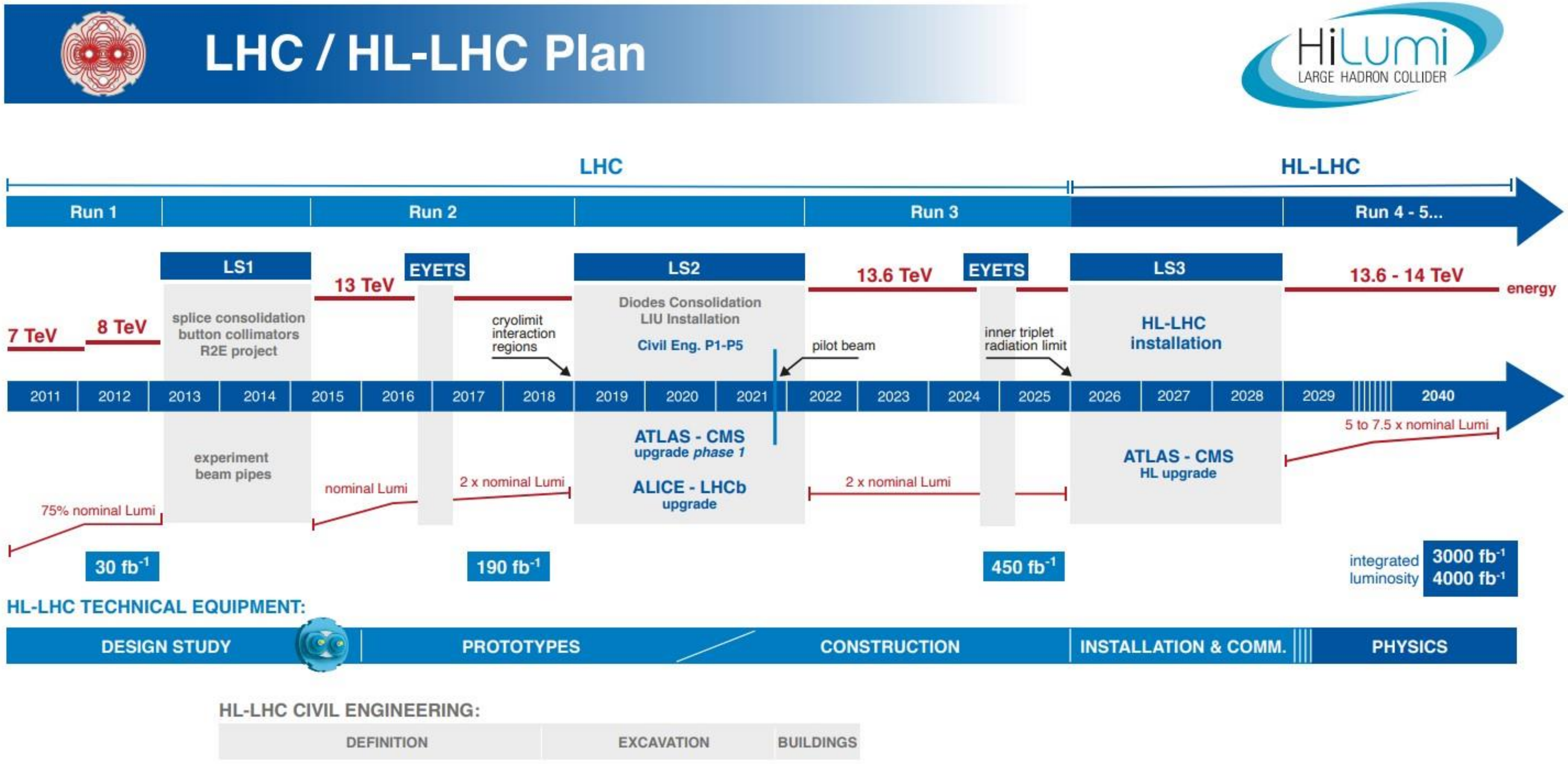


Fig.14 LHC\ HL-LHC Plan as of 07 March, 2022

The ATLAS detector

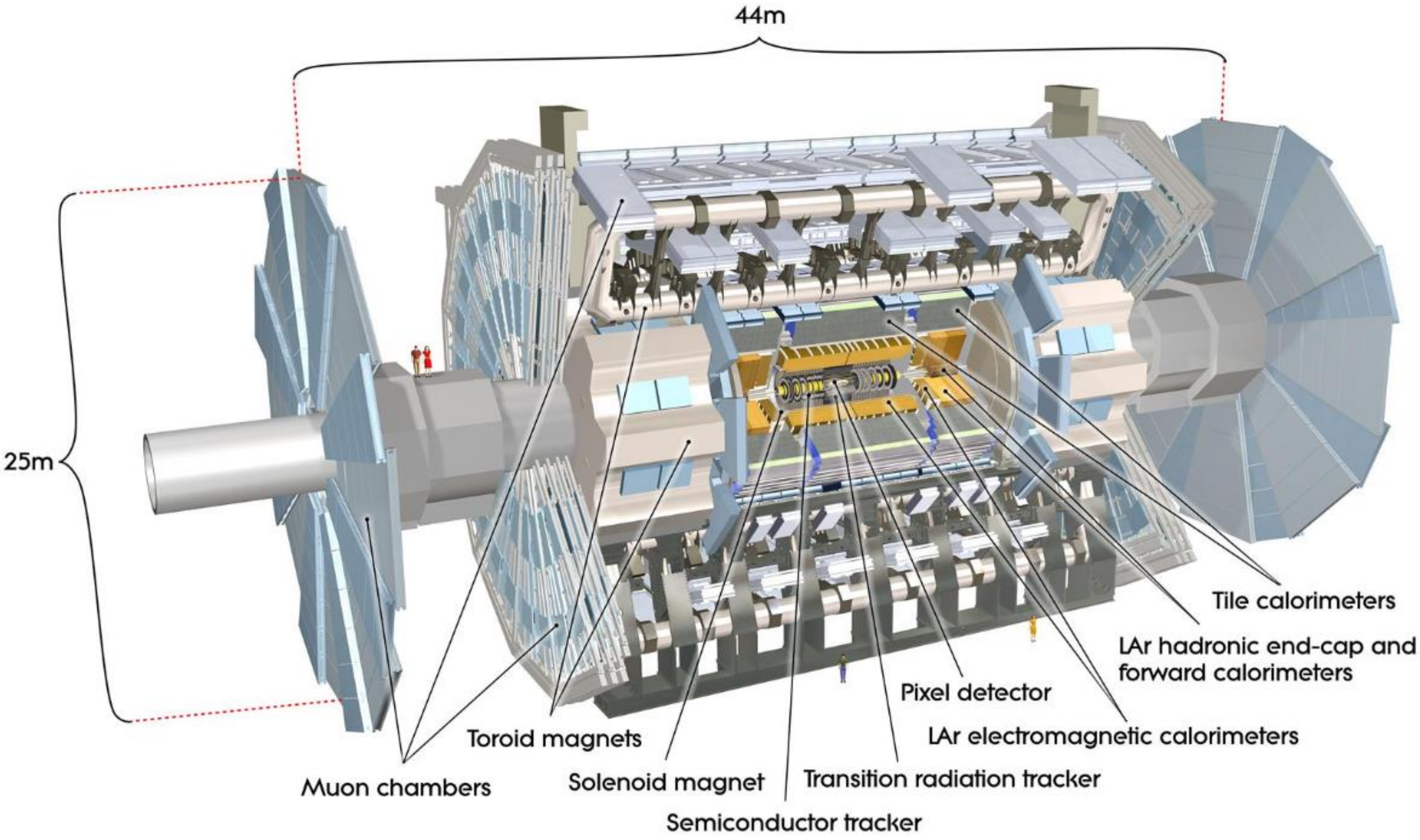


Fig.15 The ATLAS detector

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.

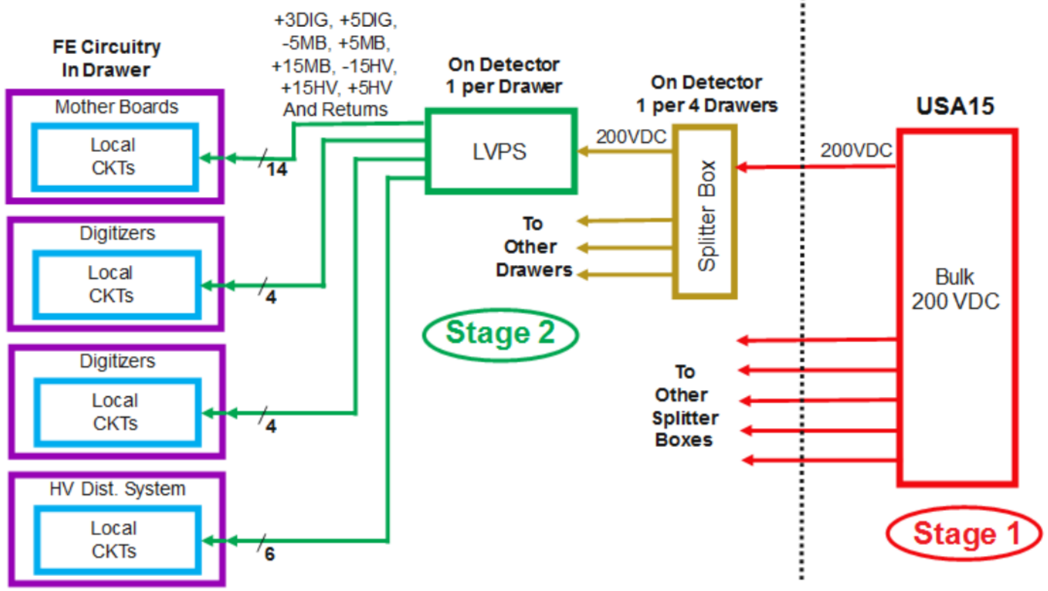


Fig.16 A Block diagram of the legacy 2-stage low-voltage system.

LV System 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;

[Technical Design Report for the Phase-II Upgrade of the ATLAS Tile Calorimeter - CERN Document Server]

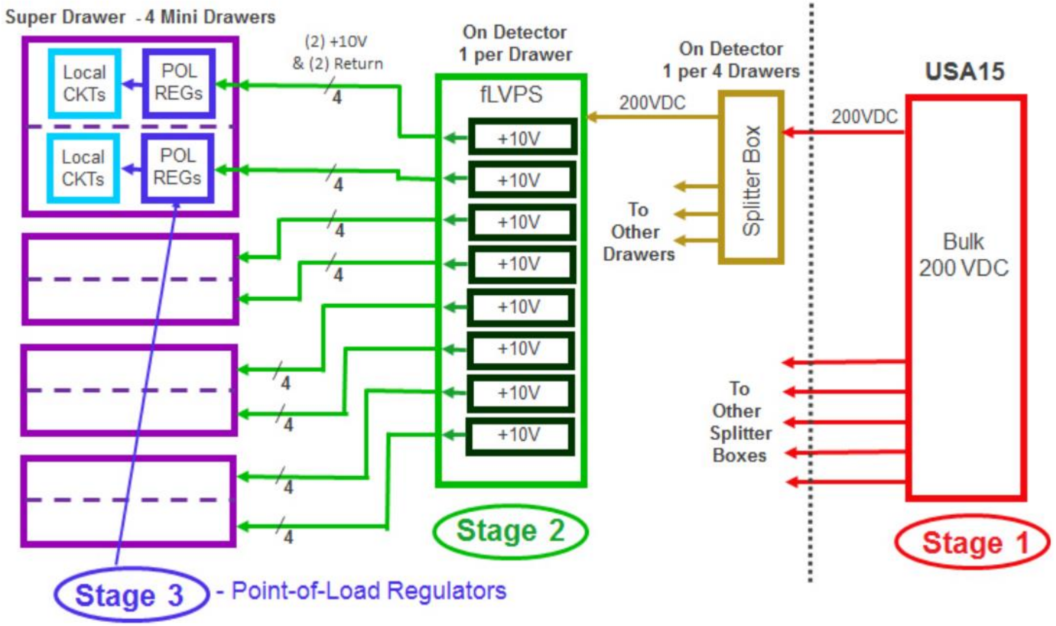


Fig.17 A Block diagram of the Phase-II upgrade 3-stage low-voltage system.

PC = Personal Computer
GUI = Graphical User Interface

Burn-in Test Station

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.
- **Electronics** – Allow for control and monitoring of the Bricks as well as 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.

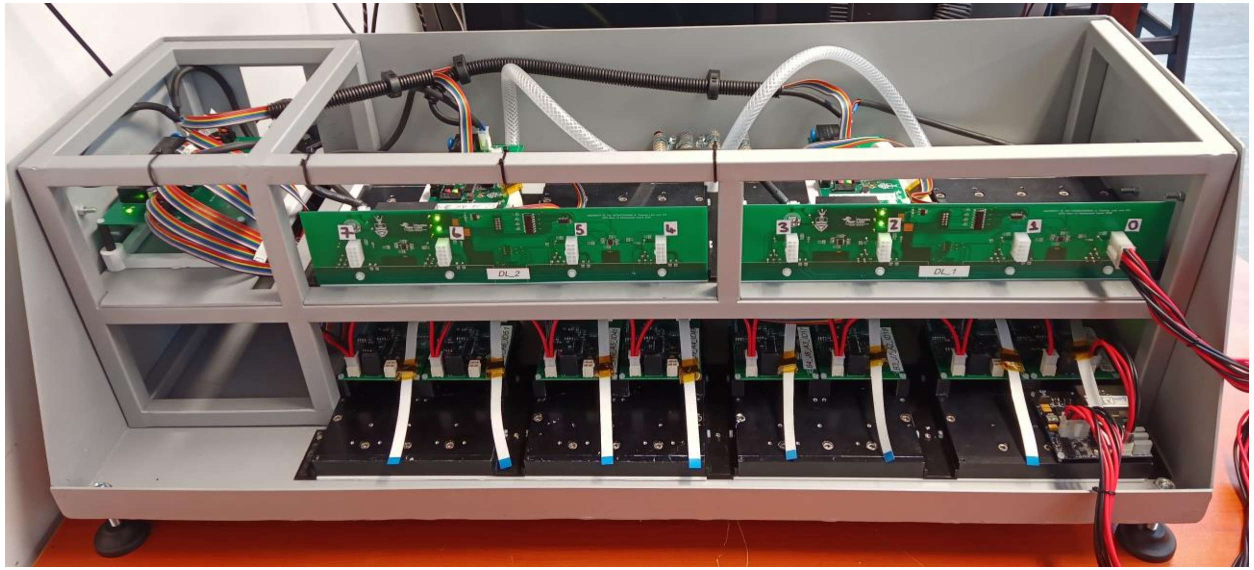


Fig.18 *Burn-in station test-bed.*

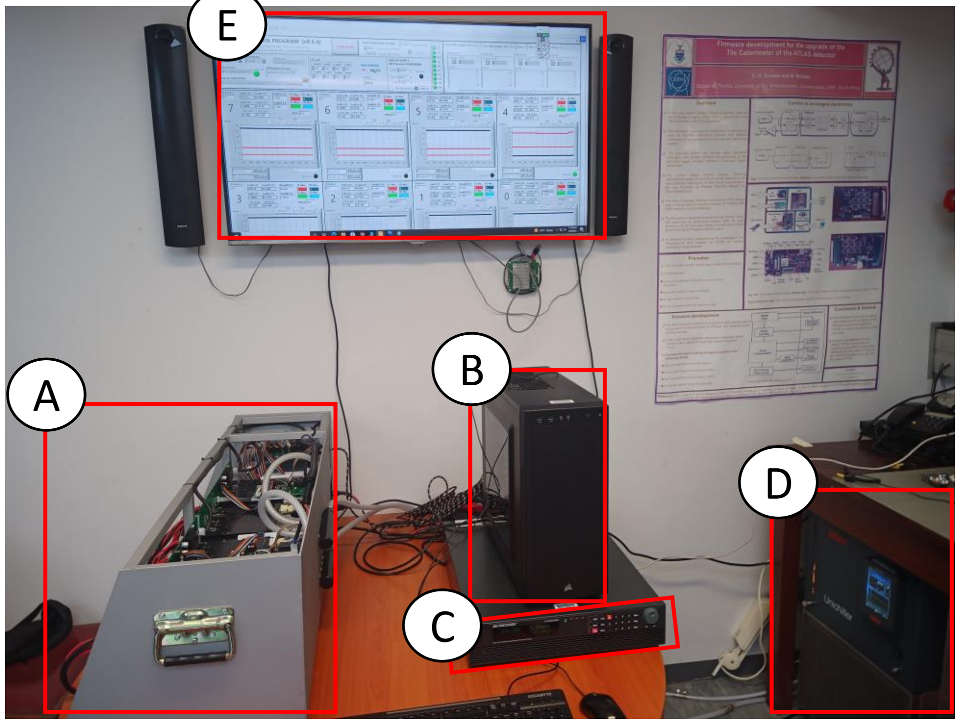


Fig.19 Burn-in test station.

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

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.

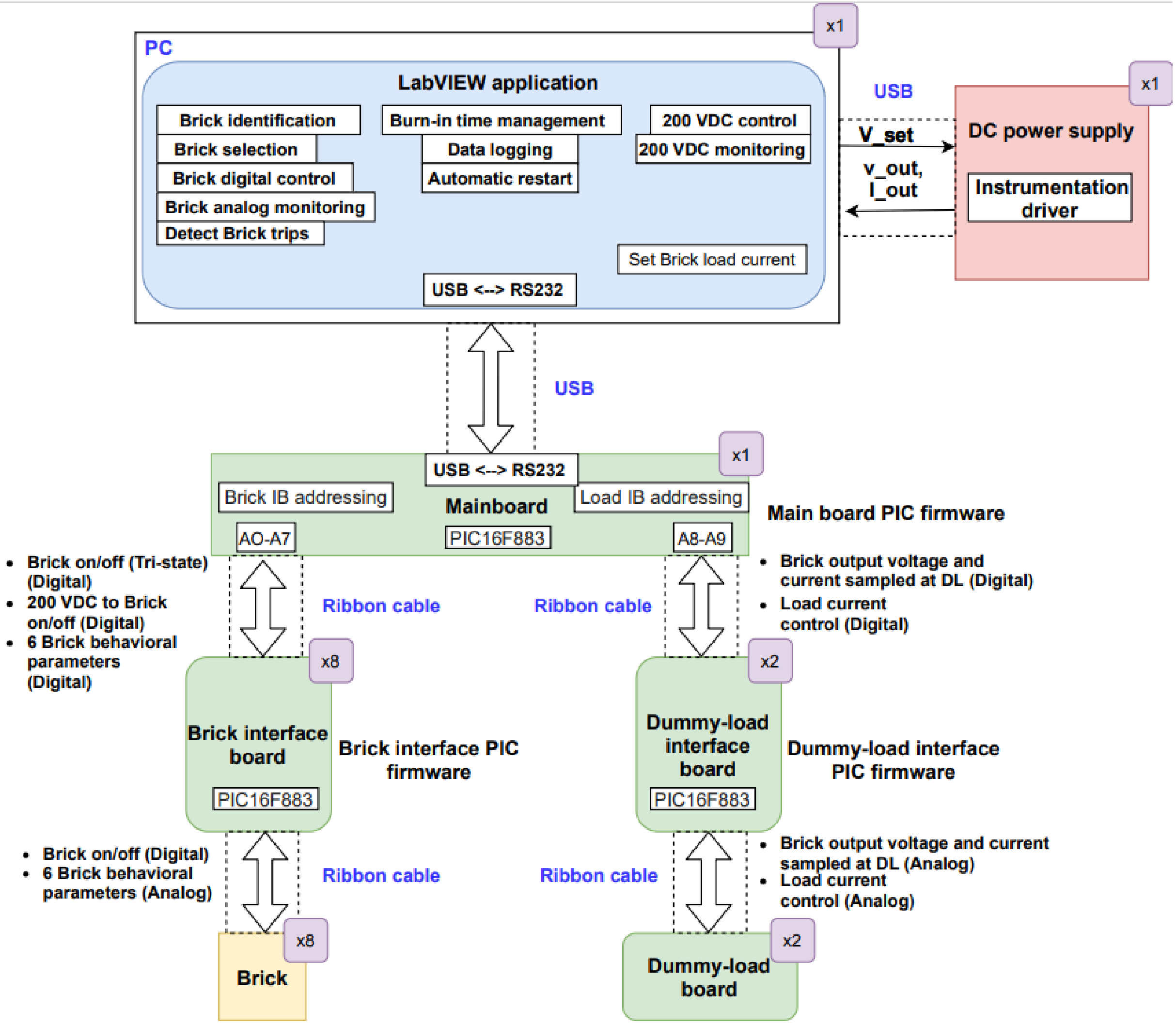


Fig.21 A simplified block diagram of the Burn-in station communication system..

Burn-in Test Station GUI

Fig.22 The Burn-in Test-Station LabVIEW GUI