South Africa's Contribution to the Upgrade of the ATLAS Hadronic Tile-Calorimeter Low-Voltage Power Supply for the HL-LHC

SAIP2025 7-11 July 2025

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The High Luminosity LHC (HL-LHC)

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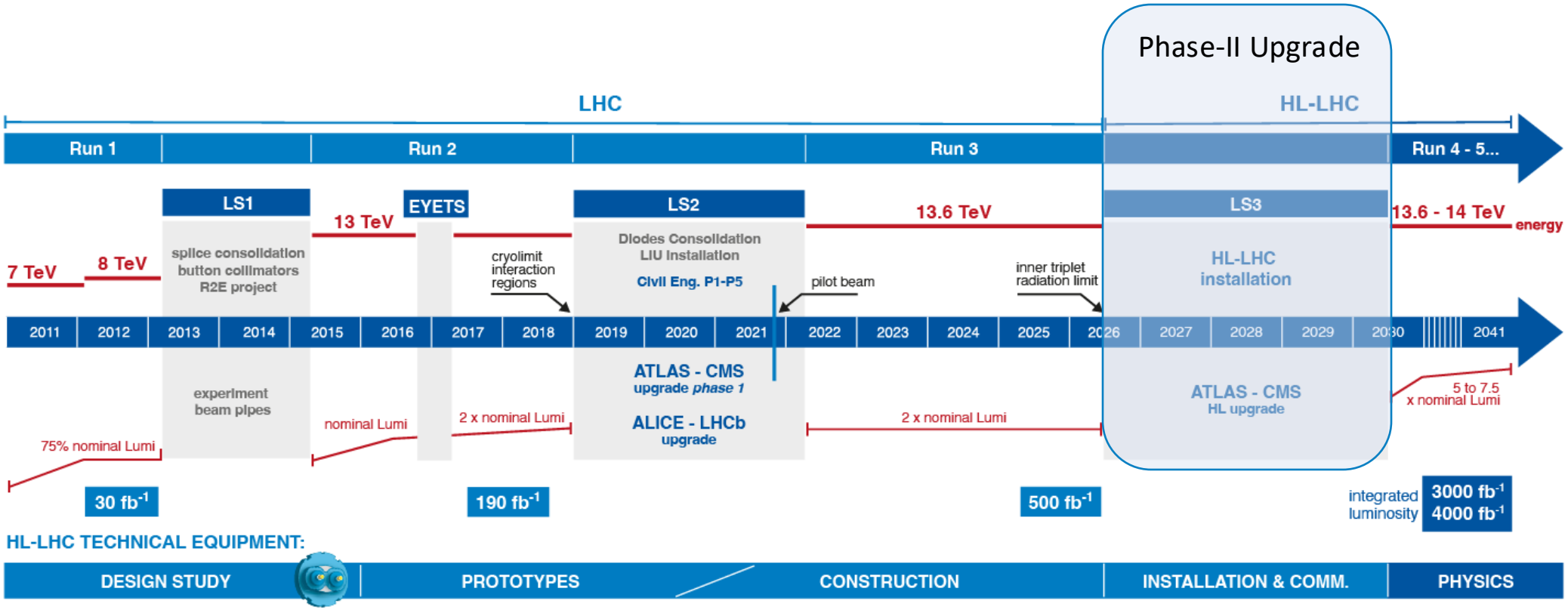
- Most of the data expected for the LHC physics program will be delivered during the HL-LHC phase.
- > 3000 fb^{-1} of data at $\sqrt{s} \simeq 14$ TeV will allow precision measurements to constrain the Standard Model in yet-unexplored phase spaces, and particularly in the Higgs sector.



Updated January 2025

ATLAS Phase-II Upgrade Overview

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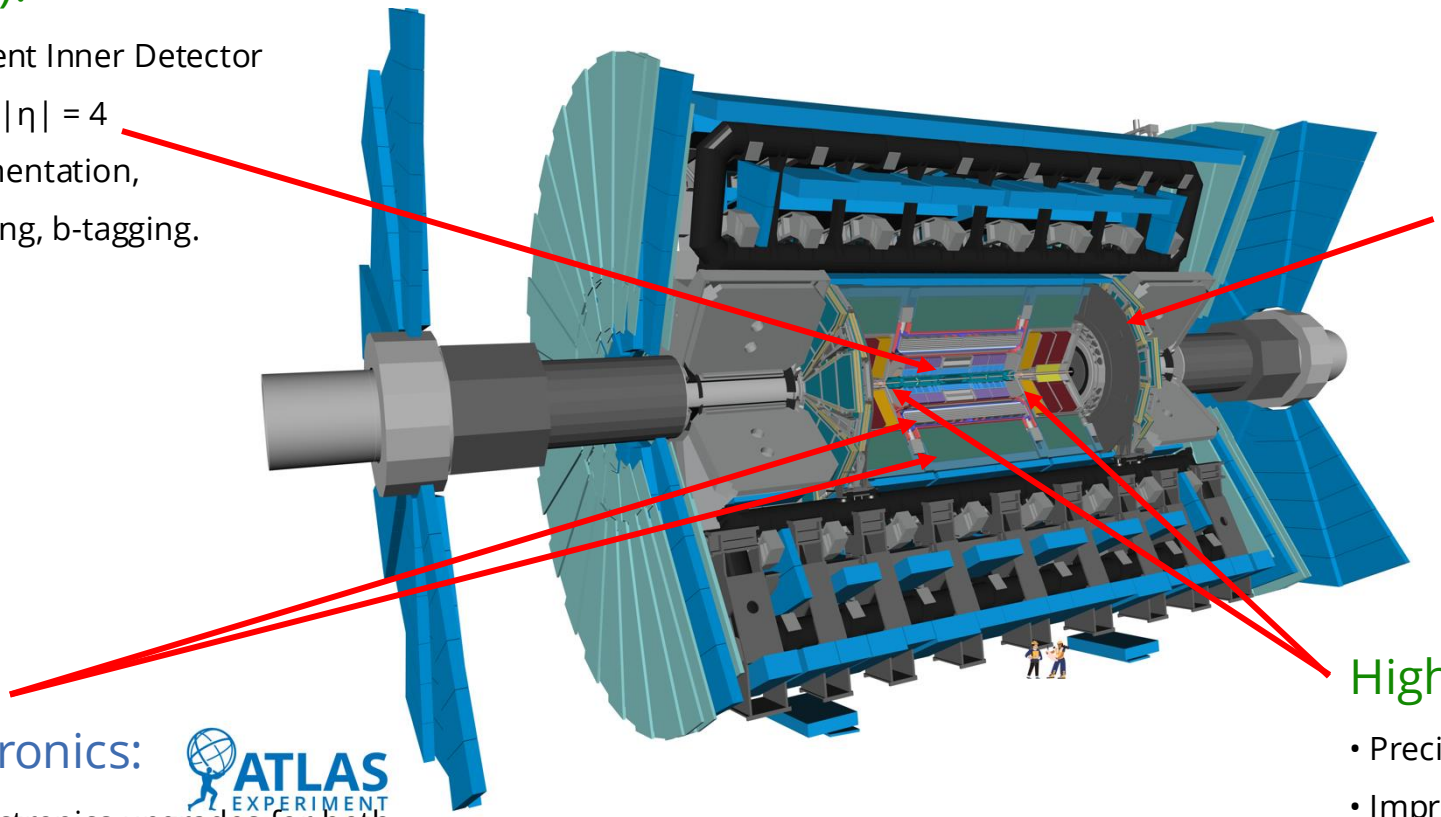
ATLAS Upgrades for the High Luminosity LHC at DIS2025 link

New and Improved detectors

Inner Tracker (ITk):

- Full replacement of current Inner Detector
- All-silicon, 9 layers up to $|\eta| = 4$
- Less material, finer segmentation, improved vertexing, tracking, b-tagging.



Muon Spectrometer:

- New Inner-Barrel chambers
  - Improved trigger efficiency and momentum resolution.
  - Reduced fake rate.
- Upgrade of the detector electronics for the new TDAQ.

Calorimeter Electronics:

- On- and Off-detector electronics upgrades for both electromagnetic and hadronic Calorimeters.
- 40MHz readout for triggering.

High-Granularity Timing Detector:

- Precision time reconstruction.
- Improved pile-up rejection in the forward Region.
- Provides bunch-by-bunch luminosity.

The ATLAS Tile-Calorimeter

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- The Tile-Calorimeter (TileCal) is a sampling calorimeter that 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.

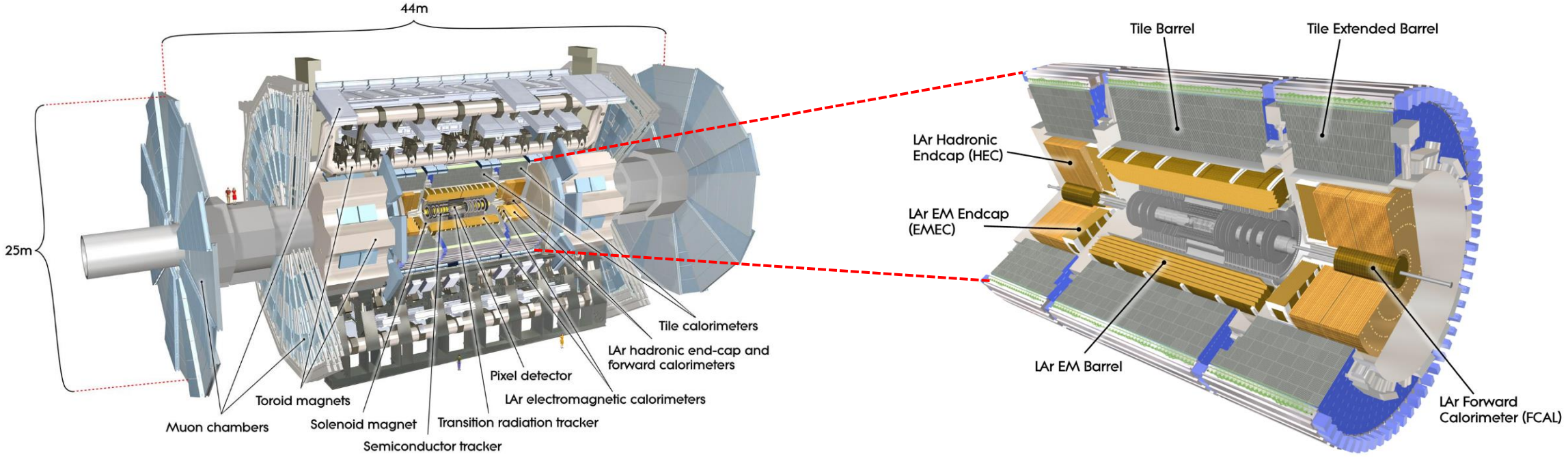

Fig. The ATLAS detector (Left). The ATLAS inner Barrel (Right) *-J. Pequenao, Computer Generated image of the ATLAS calorimeter,(2008), https: // cds. cern. ch/ record/ 1095927*

TileCal Phase-II Upgrade Overview

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- Full replacement of on- and off-detector Electronics for HL-LHC.
- Fully digital trigger readout at 40MHz for all channels.
- Redundancy introduced in data links.
- Improved radiation hardness of electronics for high luminosity environment.
- New mechanical frames to house the front-end electronics.
  - Segmented to improve accessibility and maintenance.
- **Improvement of HV and LV power systems**
  - Unified LV output with improved redundancy.
  - Redesigned with remote regulation of individual PMTs
- Upgraded calibration systems
  - Cesium electronics and hydraulic system, Laser and optics.
- Replacement of 10% of PMTs associated with the most exposed cells.

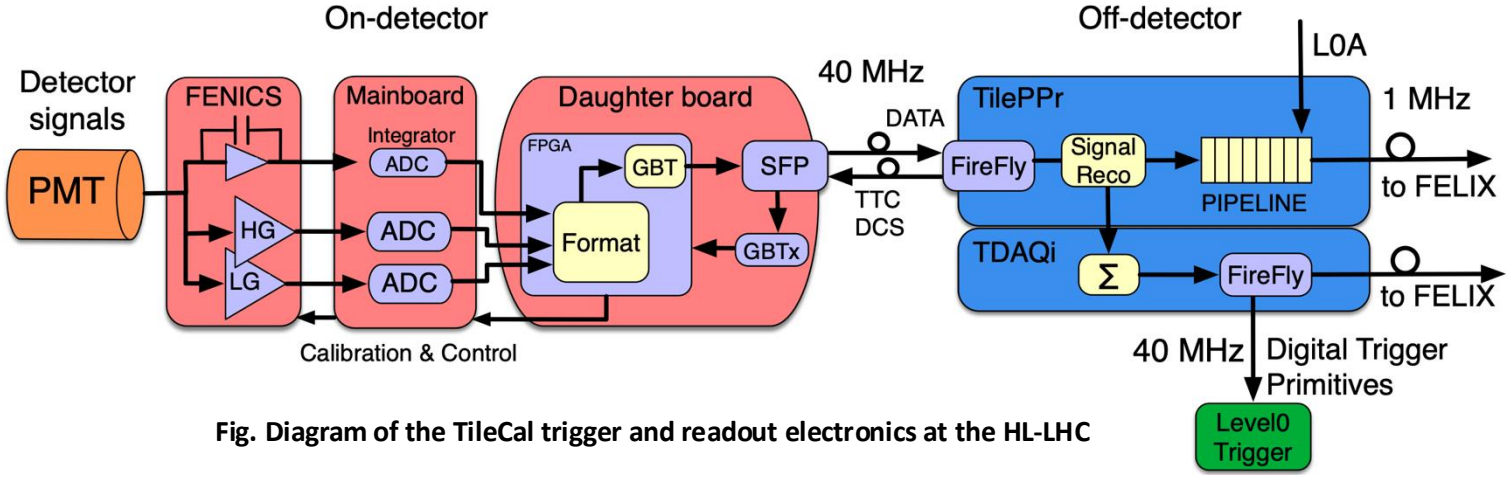

Fig. Diagram of the TileCal trigger and readout electronics at the HL-LHC

Phase-II Upgrade Low-Voltage Power Supplies

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ATLAS collaboration Week June 2025 Talk Link

- On-detector Low-Voltage Power Supplies (LVPS) provide 10 V DC to the front-end electronics of the TileCal.
- LVPS contain DC-DC step down converters.
  - An iterative design based on legacy hardware with several improvements.
    - Great emphasis is placed on their reliability and radiation tolerance.
- South Africa is locally producing 50% of the Bricks required on-detector.
  - The utilization of local manufacturers was emphasized.

Locally produced elements:
- ✓ Printed Circuit Boards (PCBs).
- ✓ Ceramic posts and their metallization.
- ✓ Production of the final device.

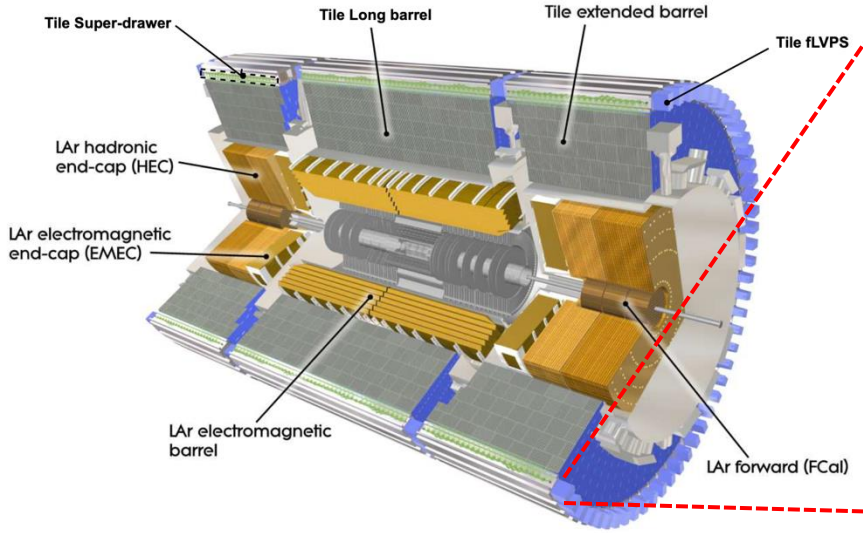

Fig. *ATLAS inner barrel.*

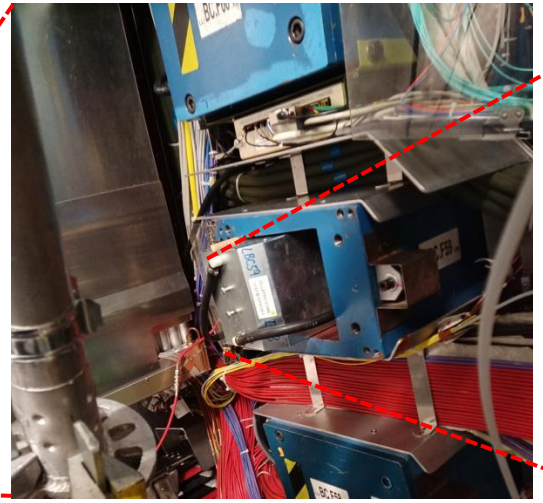

Fig. *An LVPS inside TileCal.*

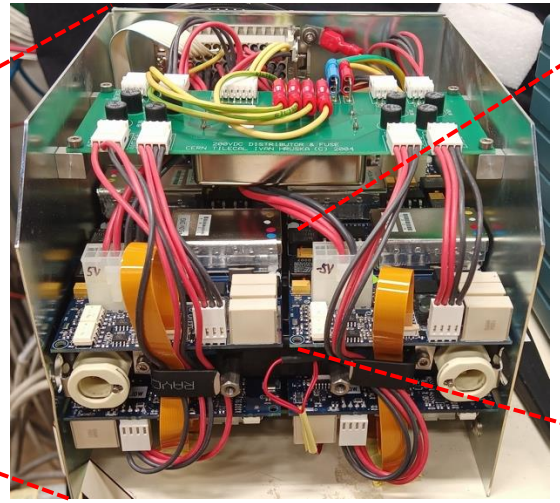

Fig. *Inside an LVPS.*

Fig. *Top view South African Brick.*

DC-DC Step-down Converter Development

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- Thermal optimization led to an increase in power efficiency from 60% to 75%.
- Required replacement of a Power MOSFET, which then required radiation tolerance assessment.
- Contributed to multiple test-beam and irradiation campaigns.
- Responsible for reliability analyses such as determining the Brick mean-time-to-failure.

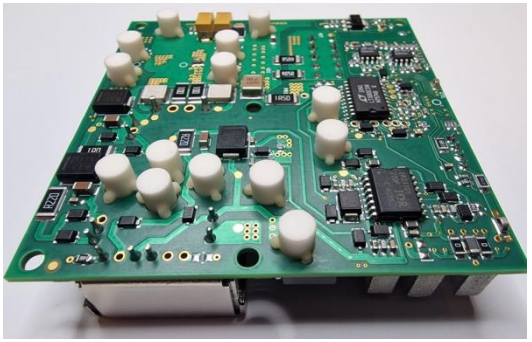


Fig. *Bottom view South African Brick.*

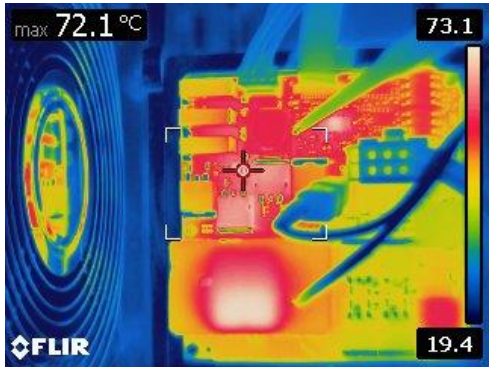


Fig. *image of the previous "inefficient" Brick.*

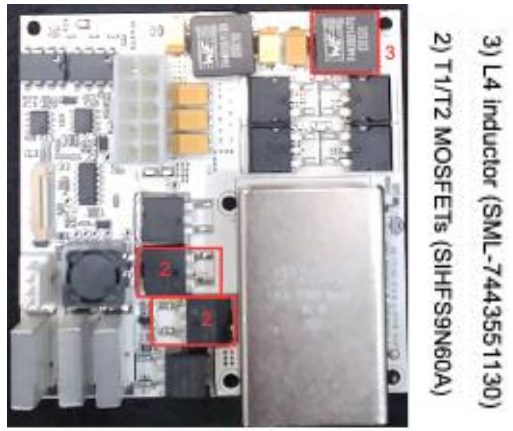


Fig. *Prototype "high-efficiency Brick.*

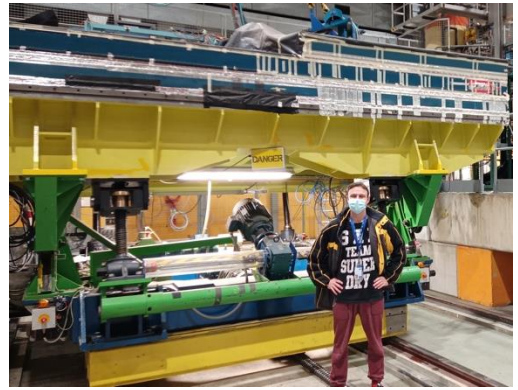


Fig. *TileCal Test-beam H8 beamline.*

Fig. *South African non/metalized posts.*

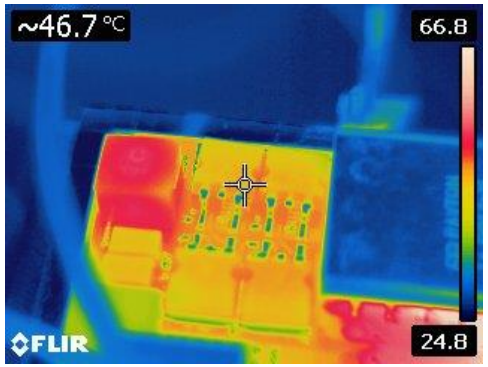
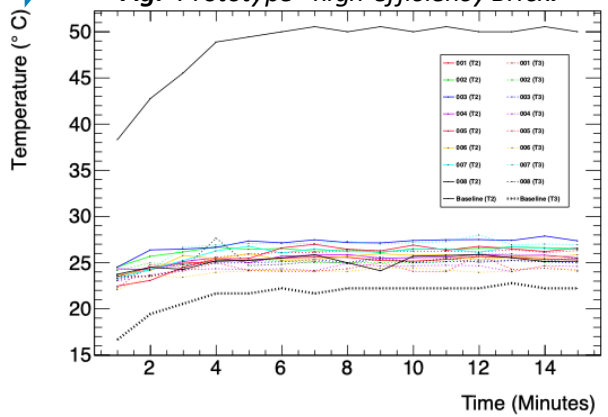


Fig. *image of the previous "inefficient" Brick.*



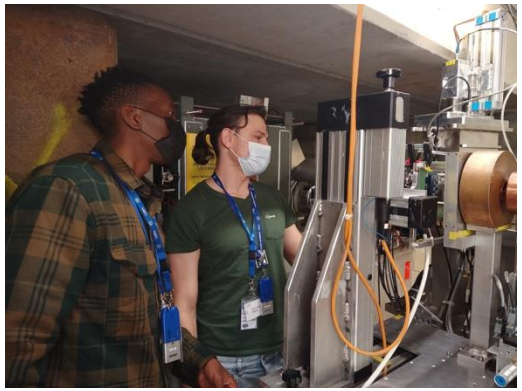


Fig. *Irradiation campaign at Paul Scherrer PIF.*

DC-DC Step-down Converter Quality Assurance

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- Due to the converters being located within the Inner-barrel of ATLAS access to them is on the order of once per year.
  - Therefore, any failures will persist for up to a year.
- Reliability is a key concern and as such a rigorous quality assurance procedure is to be implemented.
- The procedure consists of a visual inspection, Initial testing, Burn-in testing and Final testing.
- **Initial testing**: Verifies performance metrics once received from the manufacturer.
- **Burn-in testing**: Performs accelerated aging of the electronic components.
- **Final testing**: Verifies performance metrics once more to ensure that Burn-in testing did not cause any damage to the Bricks.

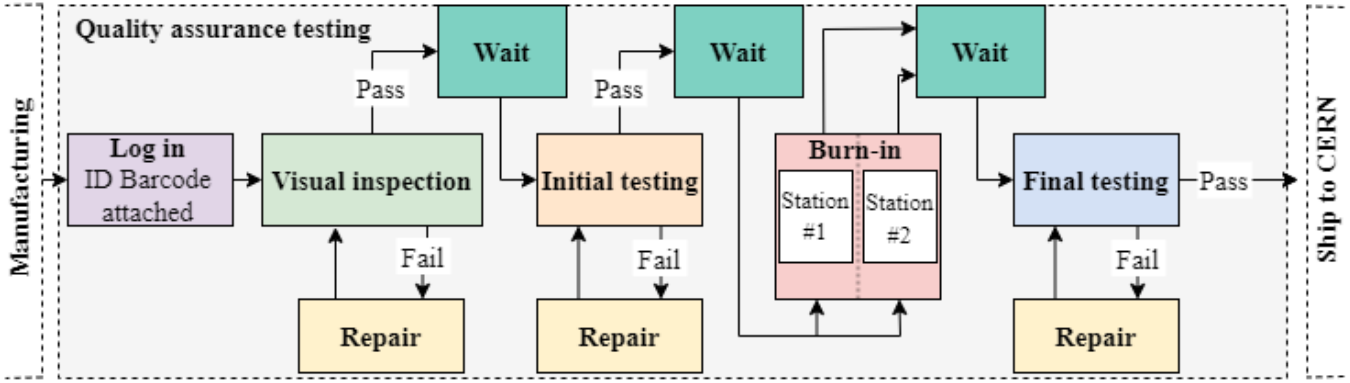

Fig. *Quality assurance testing of an LVPS Brick.*

Quality Assurance Test Stations

- Quality Assurance (QA) testing of the power converters requires the use of custom test stations due to their uniqueness.
- Two of each station type (Initial/Final and Burn-in) will be used to undertake the QA for the main production.
- One station of each type was produced for pre-production.

Scaling of QC

- Replication of QC hardware is ongoing - See the poster session contributions for further information.

Quality Assurance for LVPS Bricks in the Phase-II Tile Calorimeter Upgrade.

Mr Vongani Chabalala (University of Witwatersrand)

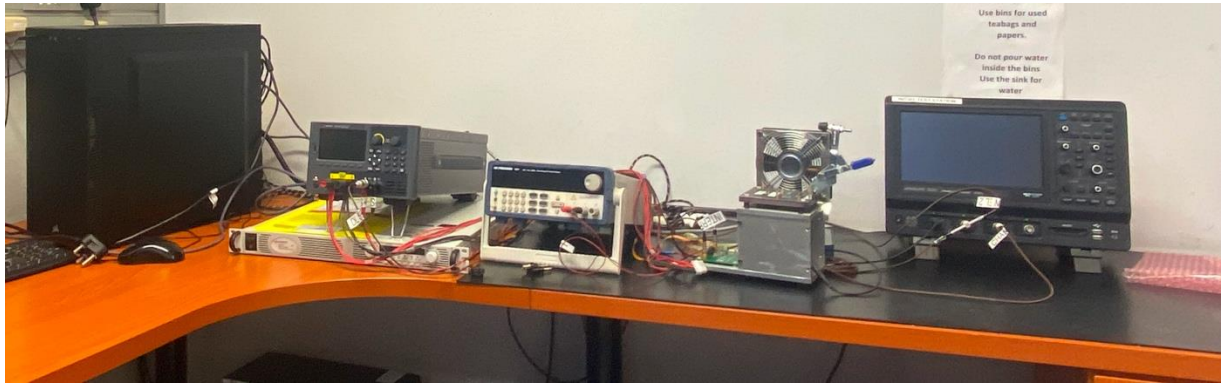

Fig. *SA single-brick test station.*

Burn-in Testing for Transformer-Coupled Buck Converters in the ATLAS Tile Calorimeter's Low Voltage Power Supplies

Thabo Pilusa (University of the Witwatersrand)

Fig. *SA Burn-in station (left), second station being brought online (right).*

DC-DC Step-down Converter Pre-Production

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- **104 DC-DC step down converters were manufactured in 2024.**
- Implemented a custom Quality Control (QC) procedure, including Burn-in testing.
  - Initial testing took place on-site at the population house.
  - Burn-in testing, 1 failure due to cold solder resulted in a short on an output inductor.
  - Observed a ~ 4% total failure rate (QC is working!).
  - Failure rate has been accounted for in our production numbers.

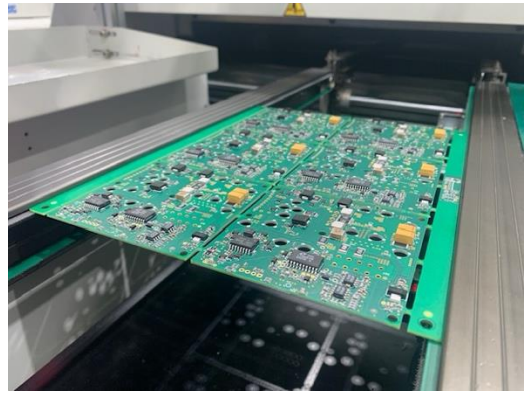

Fig. *Pre-production Brick population.*

Fig. *SA team undertaking QC.*

Fig. *Team holding first pre-production Brick.*

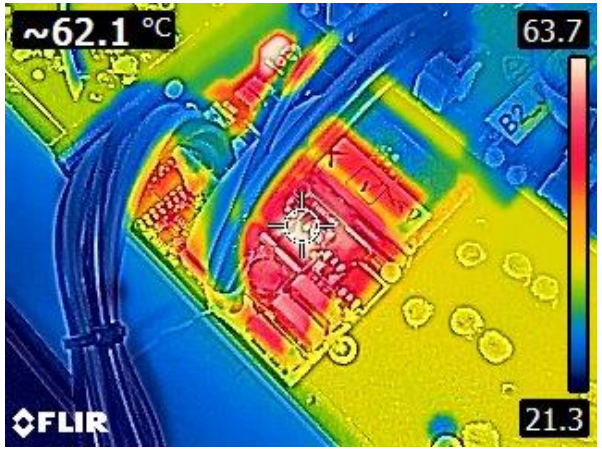

Fig. *Pre-production Brick burn-in..*

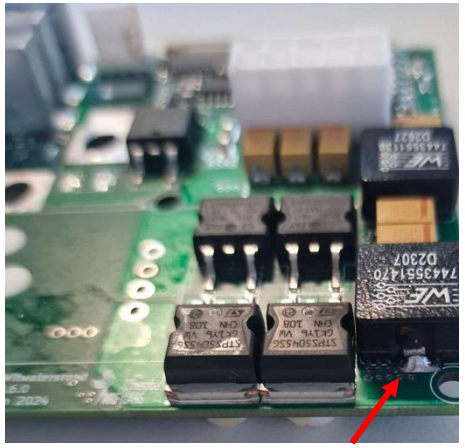

Fig. *Pre-production Brick cold solder.*

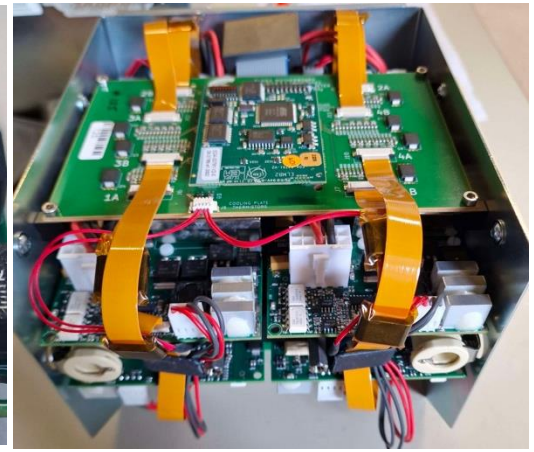

Fig. *Pre-production LVPS.*

Toward Main-production in 2025

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- Passed CERN Production Readiness Review on March 13, 2025.

- **1032 Bricks to be manufactured in South Africa.**

- To commence in **~ November 2025** and be **completed in ~ December 2025.**
- A notable effort will be required during the production due to its technical nature.
- The entire SA TileCal Phase-II Upgrade Team will be present to:
  - Assist with assembly.
  - Undertake QA in parallel.

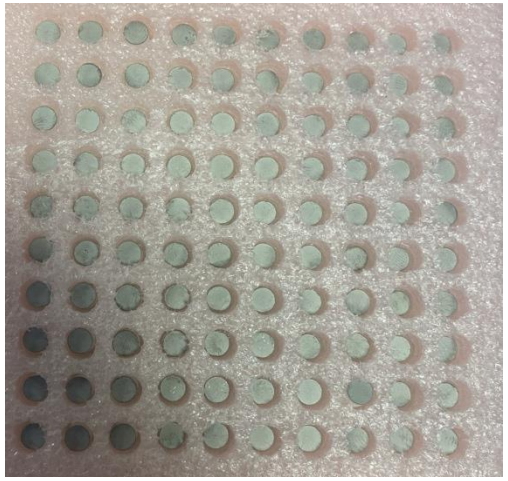

Fig. *South African main-production metallized posts..*

Current status:

- ✓ Printed Circuit Board Production is complete.
- ✓ Ceramic post production is complete.
- ○ Passive components procurement is ongoing.
- ○ Active components shipment to SA is pending
- ○ Main-production.
- ○ Main-production Quality Control.

ATLAS EXPERIMENT

ATLAS Experiment
Created March 19, 2025
Last update April 2, 2025
EDMS 3286254|ATC-R-MR-0147

3. Summary and final recommendation

The review panel acknowledges the work that went into the preparation of the review documents and the review. The review is **passed.** This recommendation will be submitted for approval to the ATLAS Technical and Upgrade Coordinators.

Executive Summary. The review is passed. The review panel thanks the team for the work invested in preparing the review, and appreciated the open and in-depth discussions. There are no show-stoppers to launching the full production, and the panel made only minor recommendations on a variety of topics.

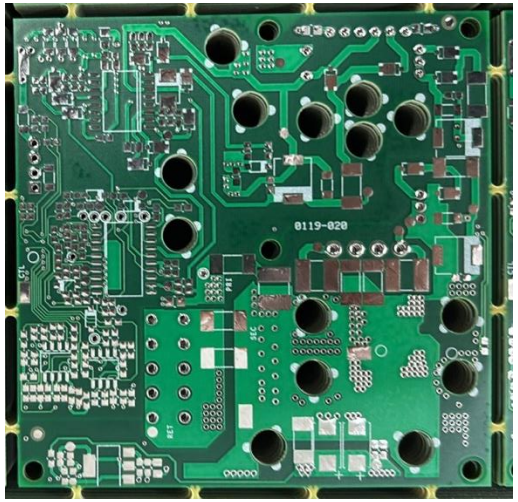

Fig. *South African main-production PCB.*

Toward Long Shutdown 3

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- The project does not end with the production and quality assurance of the power converters.
- South Africa will play a significant role in the final assembly of the Phase-II Upgrade LVPS.
  - Training of all team members is ongoing.
- South Africa will also assist with the installation of the LVPS on detector during LS3.

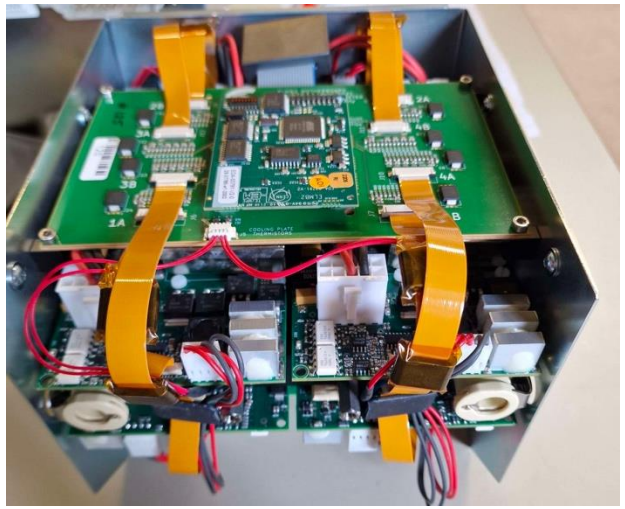

Fig: Assembly of a Wits LVPS.

Fig: Fully populated LVPS.

Fig: SA team discussing LVPS assembly at CERN.

Summary and Outlook

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- Research and development of the Phase-II LVPS Brick is complete.
- Pre-production is complete with QC functioning as intended.
- Production Readiness Review passed.

Main-production:

  - Preparations are well underway.
    - Local PCB and ceramic post production is complete.
    - Passives are currently being procured.
  - Production to commence in **~ November 2025** and be **completed in ~December 2025**
  - **QC to be completed ~ Feb 2026.**

- QC Test- stations are currently being replicated.
- Training of the SA TileCal Phase-II Upgrade team for the assembly of LVPS is ongoing.

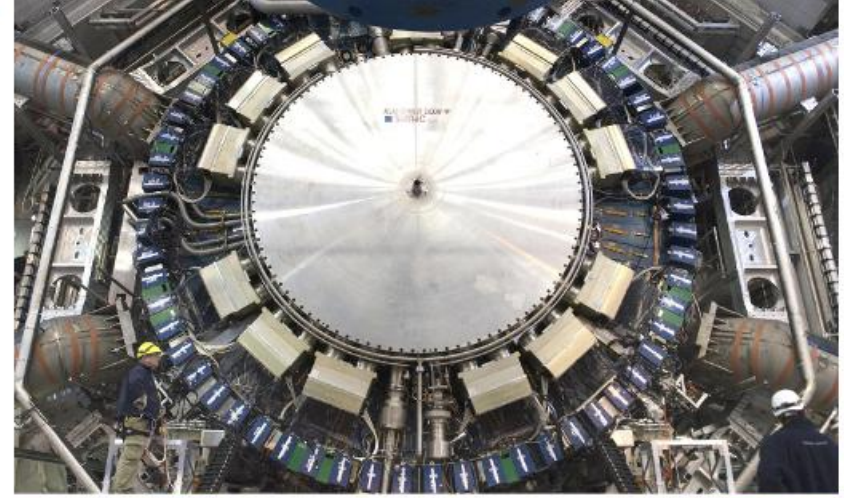
Outlook – Project on track!

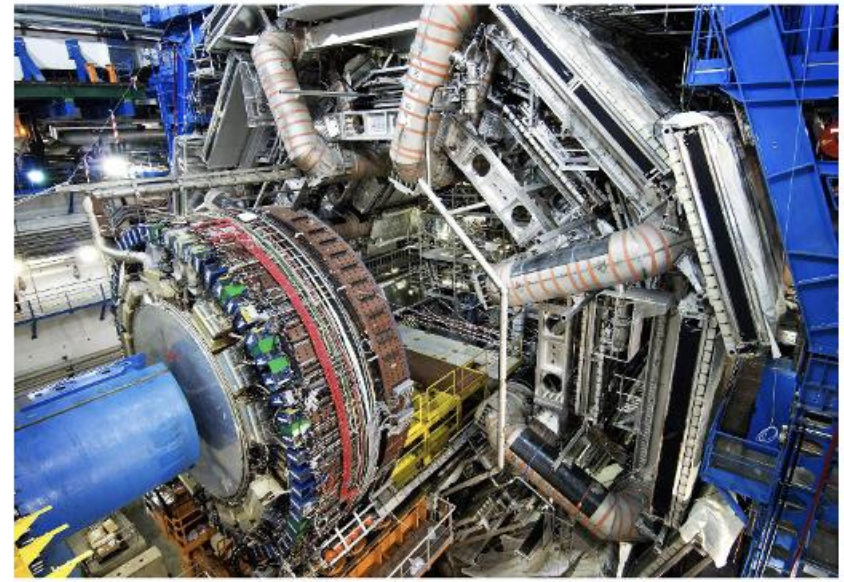
INVITATION

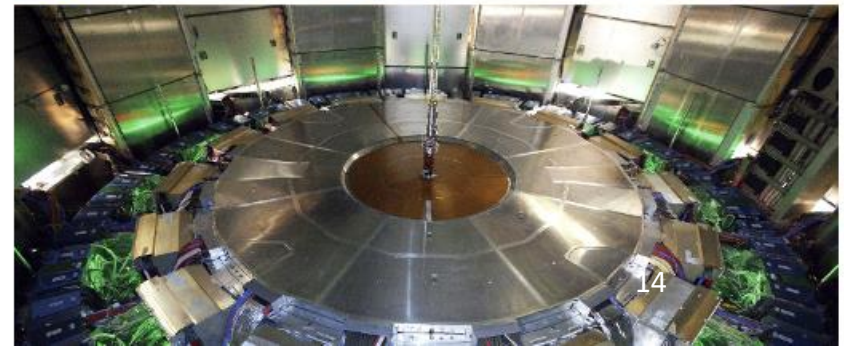
29 September **TO**
3 October 2025
NRF-iThemba LABS

TileCal Week (Outside CERN) 2025

THE SA-ATLAS PILLAR OF THE SA-CERN CONSORTIUM will be **HOSTING THE TILECAL WEEK** from 29 September to 3 October 2025 **AT NRF-ITHEMBA LABS**. The event brings together researchers, engineers, and students to discuss critical upgrades and advancements in ATLAS Hadronic Tile-Calorimeter (TileCal) technology, and serves as a vital engagement between our local scientific community and global experts. More information is available at: https://indico.cern.ch/event/1513435/







ATLAS

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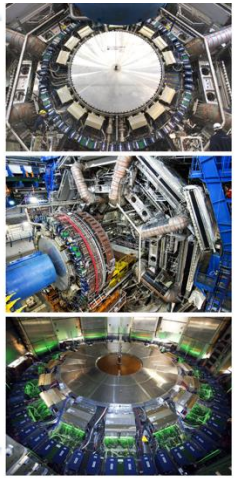

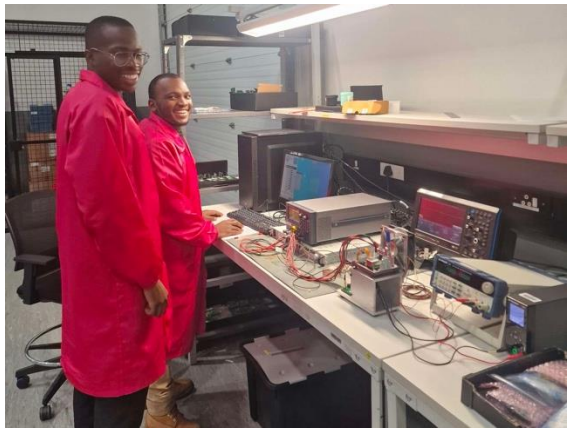

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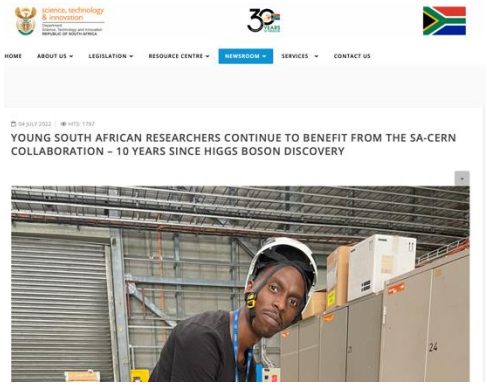
A NODE FOR AFRICAN THOUGHT

Thanks for your attention.

NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences



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TileCal Phase-II Upgrade Low-Voltage System

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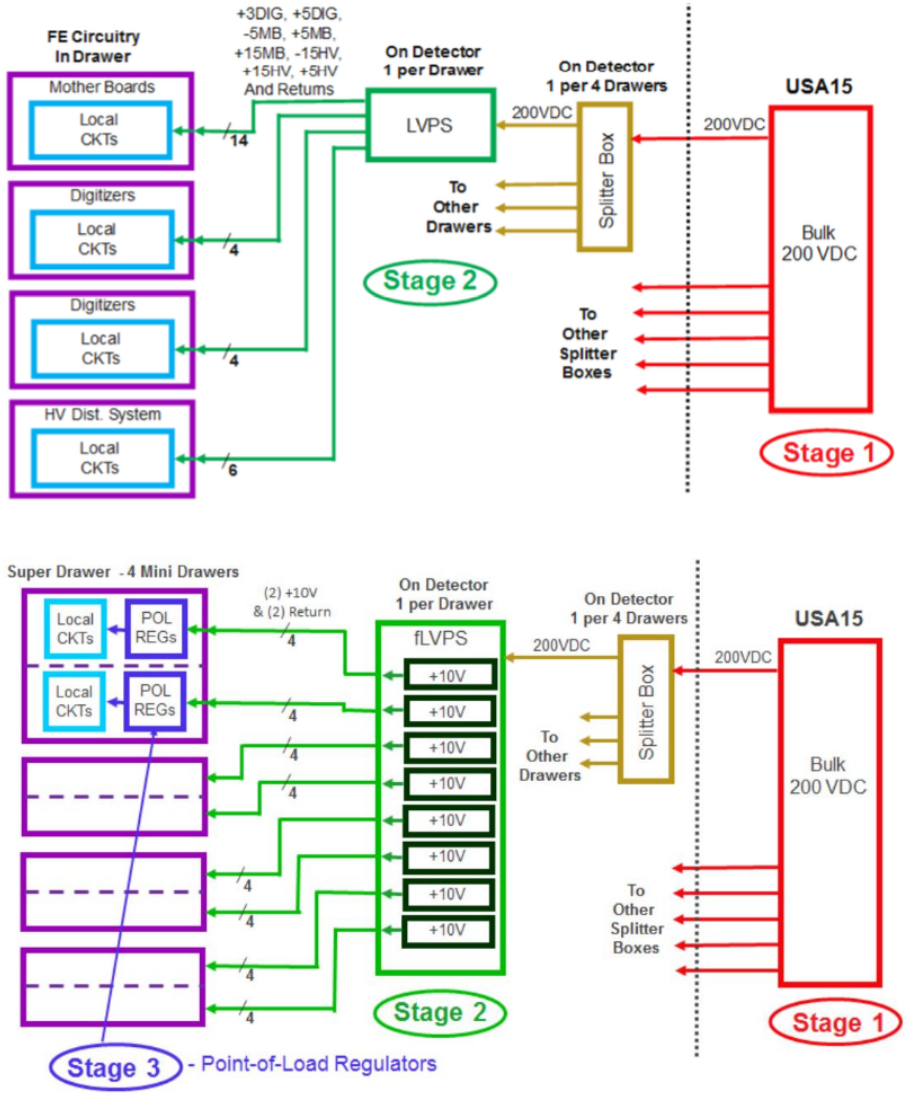
Legacy Low-Voltage System

- A **2-stage system** in which Bulk 200VDC 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.

LV System Upgrade

- **Conversion to a 3-stage system** which makes use of Point-of-load regulators (POLs). POLs function to step-down the 10VDC 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 LV Brick;
- An extensive **radiation campaign** is underway in order to validate LV system components operation within HL-LHC environment.



DC-DC Step-down Converter Burn-in Station

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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.

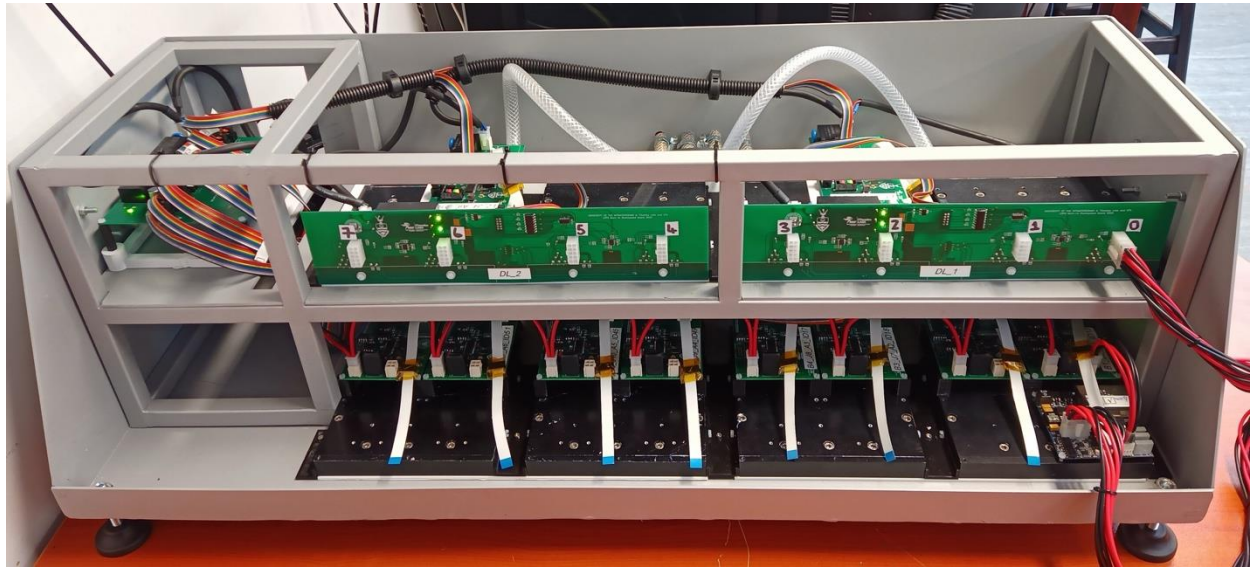

Fig.18 *Burn-in station test-bed.*

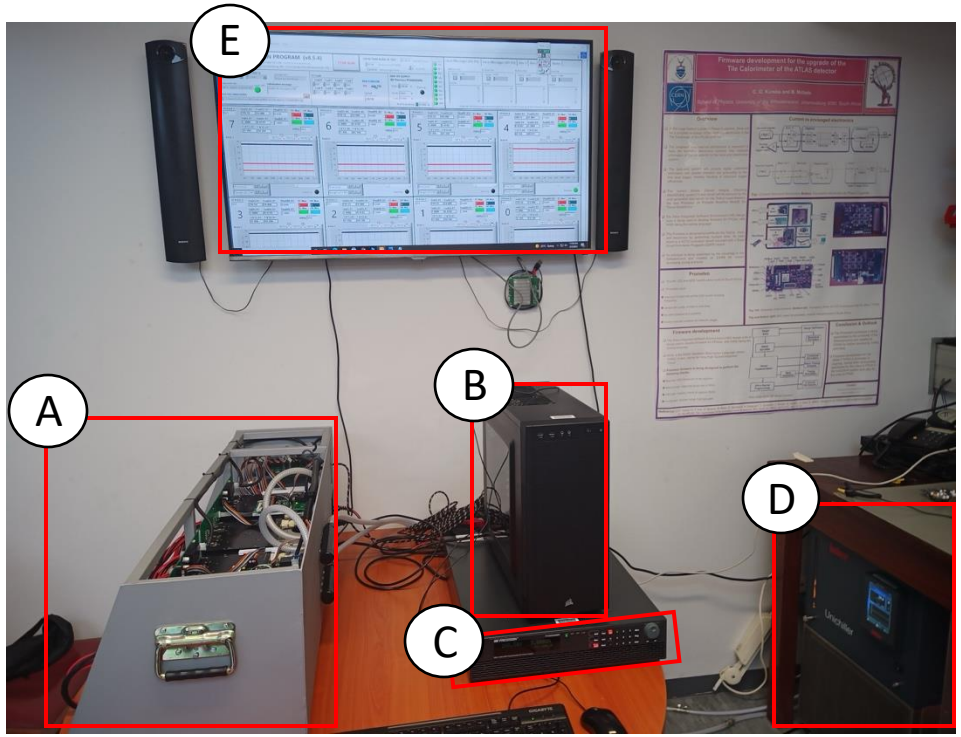

Fig.19 Burn-in test station.

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