

Advancements in Power Supply Systems for the High-Luminosity Large Hadron Collider (HL-LHC)

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ISOLDE 2025, CERN 03-05 December 2025

From LHC to HL-LHC



DESIGNED FOR LHC

- 1998

At the dawn of LHC CAEN started an ambitious R&D program to design and build a new generation of power supplies capable to cope with the demanding conditions of the new hadron collider. Many new challenges had to be faced by the engineering team who had to move in an uncharted territory without the support of detailed simulation and purposely built test facility.



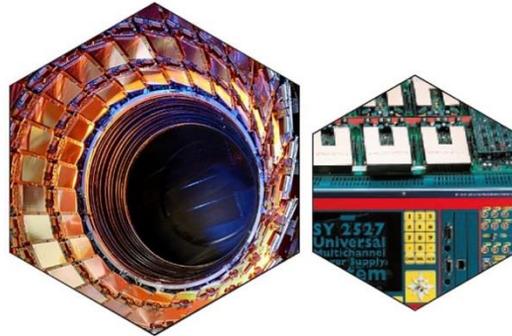
From LHC to HL-LHC



FIRST LHC PROTOTYPES

- 2000

At the beginning of the new century, in collaboration with universities and research centers, CAEN produced the first prototypes for the LHC derived from its SASY2000 family: the EASY was born. The design was driven by the research of components that were rad-tolerant up to 15 kRad and resilient to magnetic fields up to 2 kGauss.



From LHC to HL-LHC



LHC COMMISSIONING

- 2008

By the startup of the LHC more than 7000 EASY modules were built in many different variants to satisfy all experimental needs. The approach was to create a scalable system with basic building blocks that could suit various requirements, the standard catalog products constitute the backbone in “safe area” were the controls and essential services are situated, then in the hostile area there are the EASY products with its own crates, bulk power supplies and electronic boards.



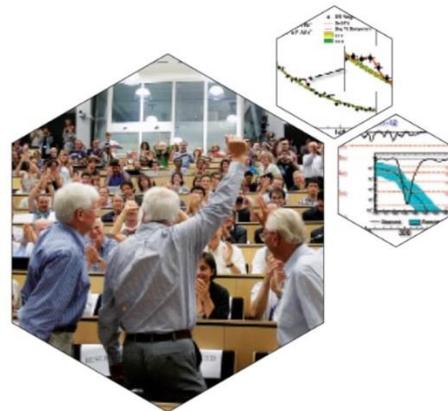
From LHC to HL-LHC



HIGGS BOSON DISCOVERY

- 2012

After 10 years from the original design and 4 years of continuous operations EASY modules performed magnificently allowing the experiments to record data with unprecedented efficiency and announce to the World the discovery of the Higgs boson July 4th 2012.



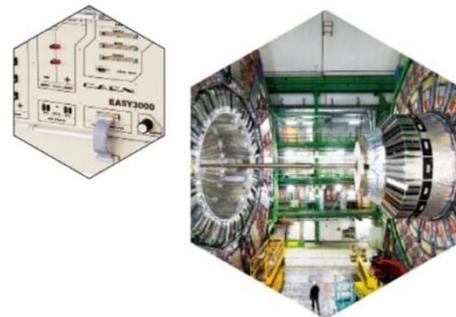
From LHC to HL-LHC



LHC RUN 2 AND FIRST UPGRADES

- 2015

During the first long shutdown of the LHC some experiments started to upgrade their systems, the EASY solution proved one more time to be effective and easily adaptable to new requirements, one of this is for sure the CMS Phase 1 Pixel upgrade where the old A4603 were modified to power DC-DC converter at 12 V rather than directly the load at ~2 V. Other detectors followed the same approach moving to DC-DC POL converters and CAEN answered with H versions of its EASY 3000 modules.



From LHC to HL-LHC

1998

2000

2008

2012

2015

2018

>2025

EASY BRIC 1

- 2018

In January 2018 a new module with enhanced resilience, tested with an integrated dose of 20 kRad and in a 5 kGauss magnetic field, was presented at CERN. The B and Rad tolerant Intermediate Converter is a simple DC-DC converter but it embodies CAEN will to pursue R&D in hostile area, providing in a small form factor a 1600 W liquid cooled converter with a power density never achieved before.



From LHC to HL-LHC



HL-LHC

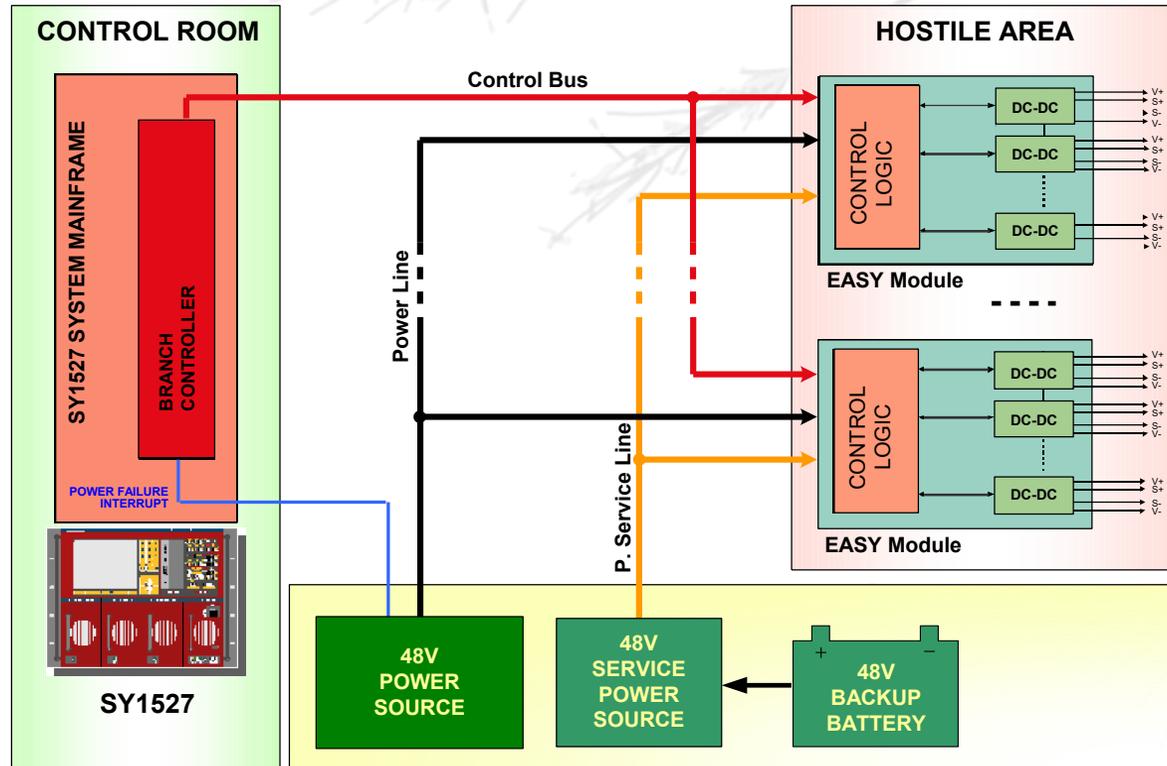
- 2025 >

High Luminosity LHC is the next step of the LHC machine, with almost double luminosity it will collect in ten years ten times the data of the first 10 years of "standard" LHC operations. The increased collisions rate will pose a serious threat to electronics, which will need improved radiation resilience to be able to operate safely in such environment. Fortunately, the knowhow gathered during the design and operation of the LHC will give the necessary background to build the new EASY6000 family.

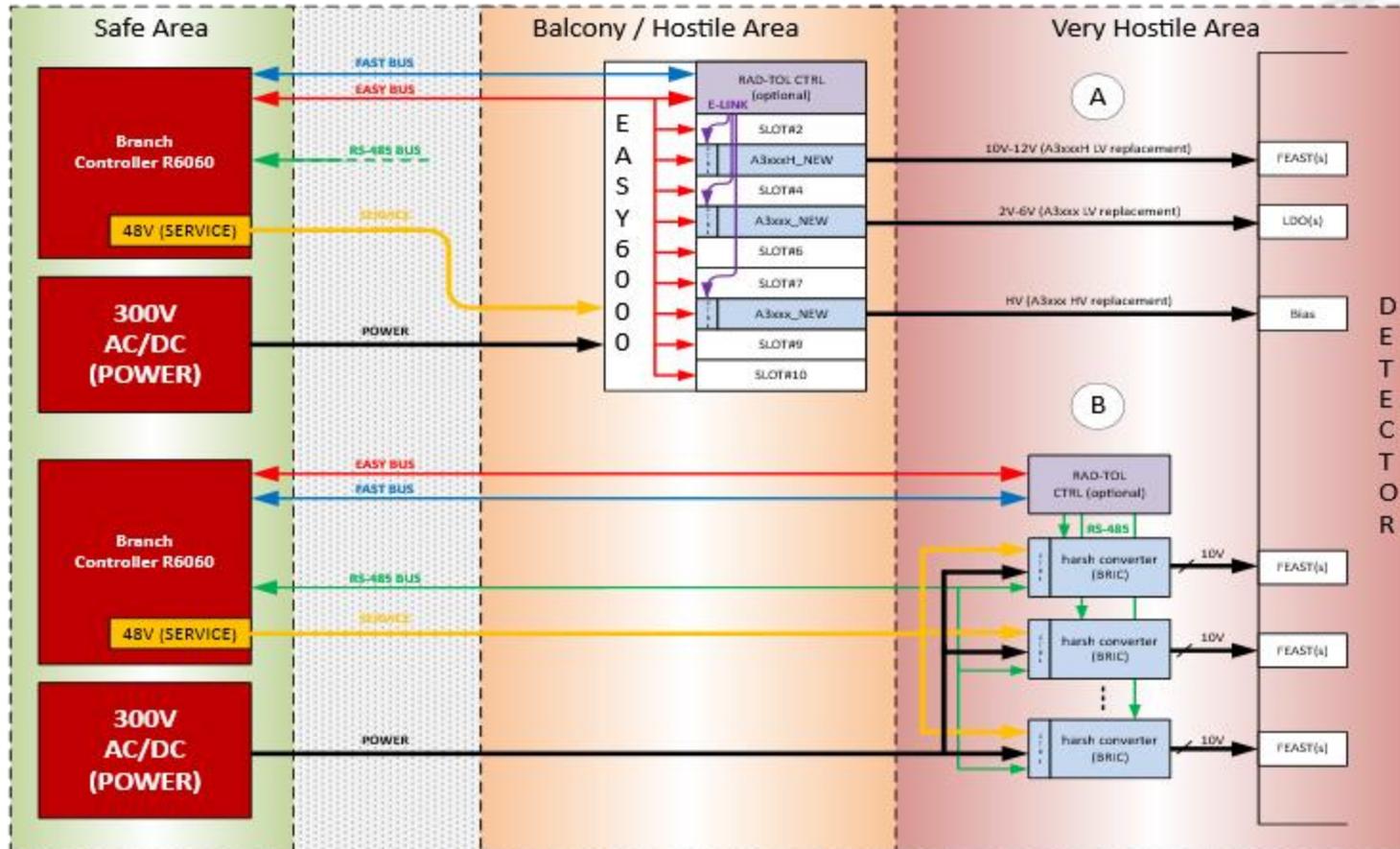


EASY3000/4000

- The old system was built as a hostile area extension of the SY1527 (now SY4527)
- It has done a great job but in the years some area of improvements have been identified:
 - Communication speed on very large installations (scalability)
 - High-power density solutions
 - Starting price for small setups



EASY6000 concept



- **Extremely flexible architecture**, allowing more configurations than the previous generation
- New harsh converters for **Very Hostile Area** (>200 Gy) to be placed closer to the detector (~m) optimizing cable power loss
- New **faster connection** to DCS thanks to the brand new R6060 branch controller with Gb Ethernet
- New **faster connection** to the EASY remote boards thanks (CAN for back-compatibility, SFP+ for high-bandwidth, RS-485 for robustness and easy implementation.
- **More power** thanks to a 300V bulk power line from service to experimental caverns:
6x higher voltage -> 6x less current -> much less cable area to have the same power efficiency or much better power efficiency keeping the same cables

EASY6000 hostile area

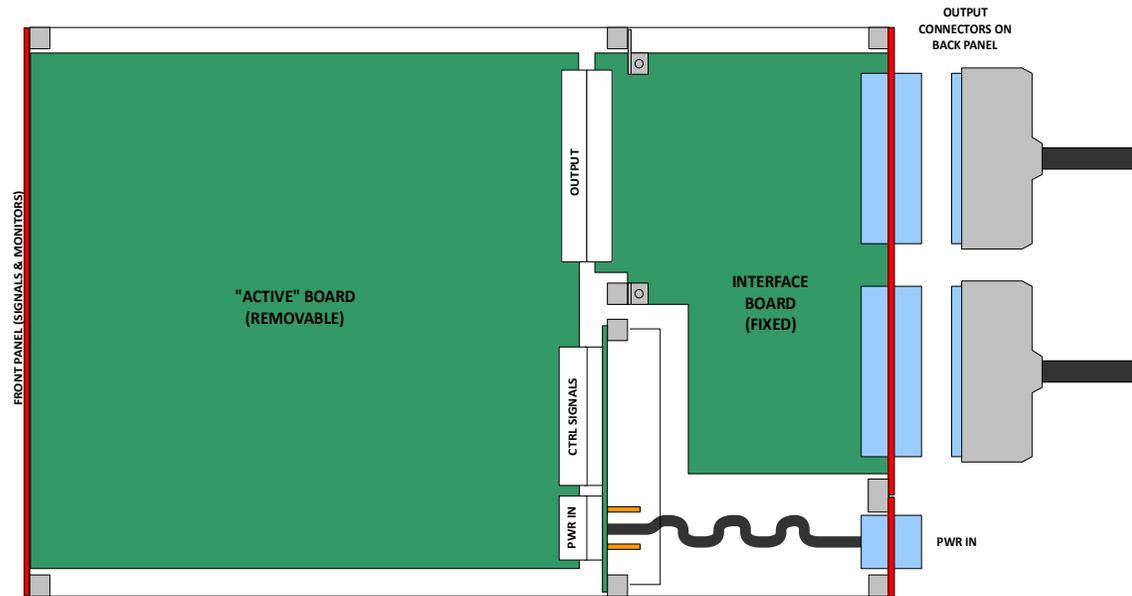
- All boards must survive the harsher conditions of the experimental caverns during HL:
 - 20 kRad total dose (200 Gy)
 - 5×10^{12} n/cm² (1 MeV Eq.)
 - 1×10^{12} p/cm² (>20 MeV)
- We resolved to **test the boards up to:**
 - **40 kRad** total dose (400 Gy)
 - **6×10^{12} n/cm²** (1 MeV Eq.)
 - **2×10^{12} p/cm²** (>20 MeV)
- Magnetic fields up to 0.6 T (tested up to 1.0 T)



EASY6000 power

- New R6060 branch controller

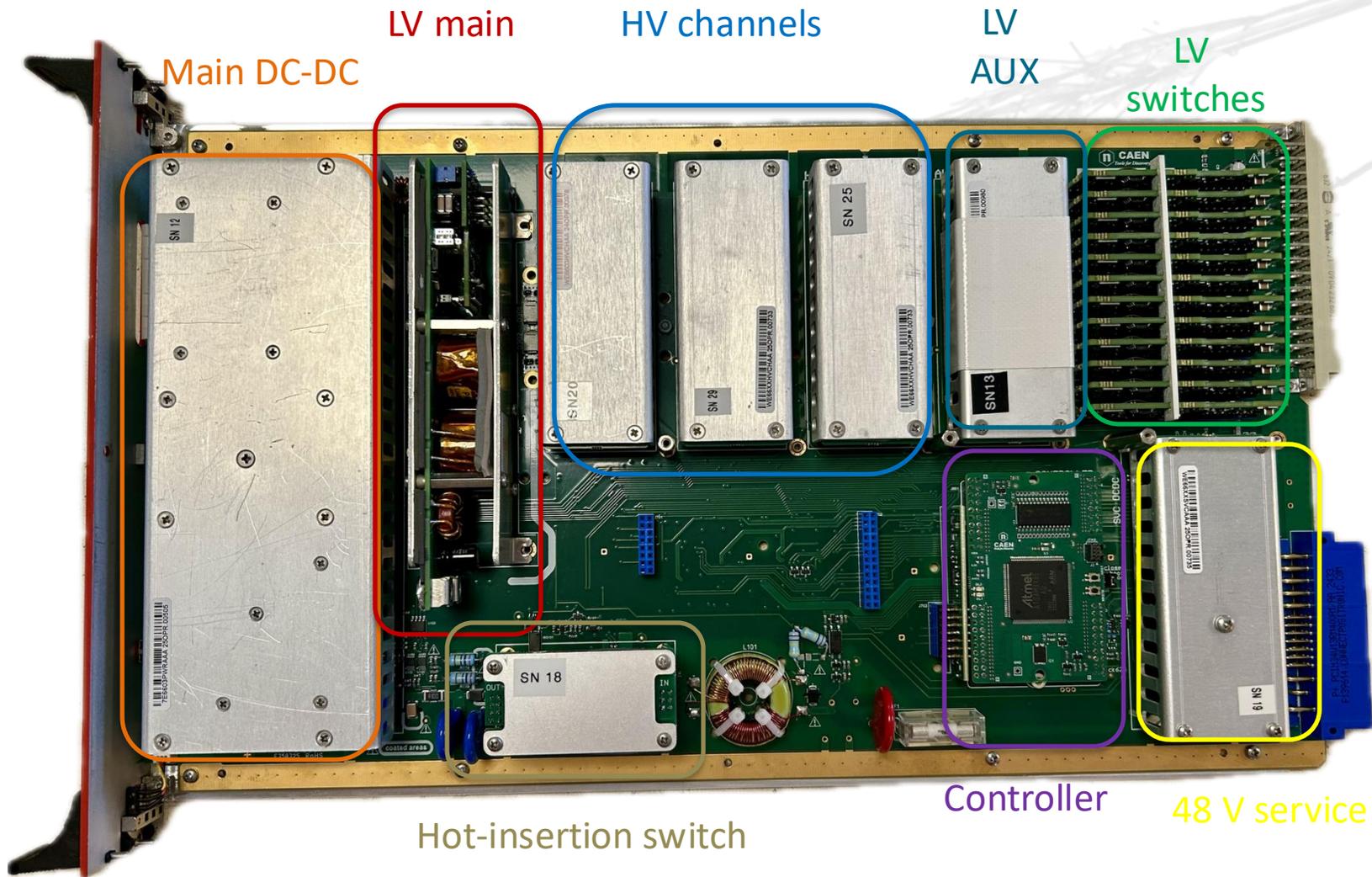
- The **independent service power** will arrive directly from the new branch controller at 48 V
- The external AC/DC power source at **300 V minimizes cable losses** to bring the necessary power from the service cavern to the experimental cavern:
 - Hp: 3kW to be delivered @48V (~60A) via AWG0000(Ø 11.7mm) 100m(x2) cable, ~115W power loss
 - Hp: 3kW to be delivered @300V (10A) via AWG9(Ø 2.9mm) 100m(x2) cable, ~100W power loss only (95% power efficiency)
- This choice will help the **maintenance** of the bulk **AC-DC** converters thanks to their location in safe area.



EASY6000 family

- The boards will be **adaptable** via a back/interface-board to various cable types
- The back/interface-board will ensure an easy and fast swap between boards, so the maintenance time spent in *Controlled Radiation Areas* is minimal according to the **ALARA principles**

- The **safety of the system** is granted thanks to many precautions:
 - Careful component and system tests in hostile environment (several MOSFETs, BJTs, PWM ICs, analog ICs, Vref, Opamp, Data converters, Drivers,... tested during last 3 years in H.E.)
 - Robustness of the most delicate circuits ensured by design (component de-rating, selection of best circuit topologies, proper devices biasing strategy,...)
 - Redundancies where needed (both in HW, FW and SW)
 - Advanced Diagnostics: sensors and on-board algorithms to predict and avoid failures (thanks to the ongoing PRIMIS R&D project)



A6603 structure

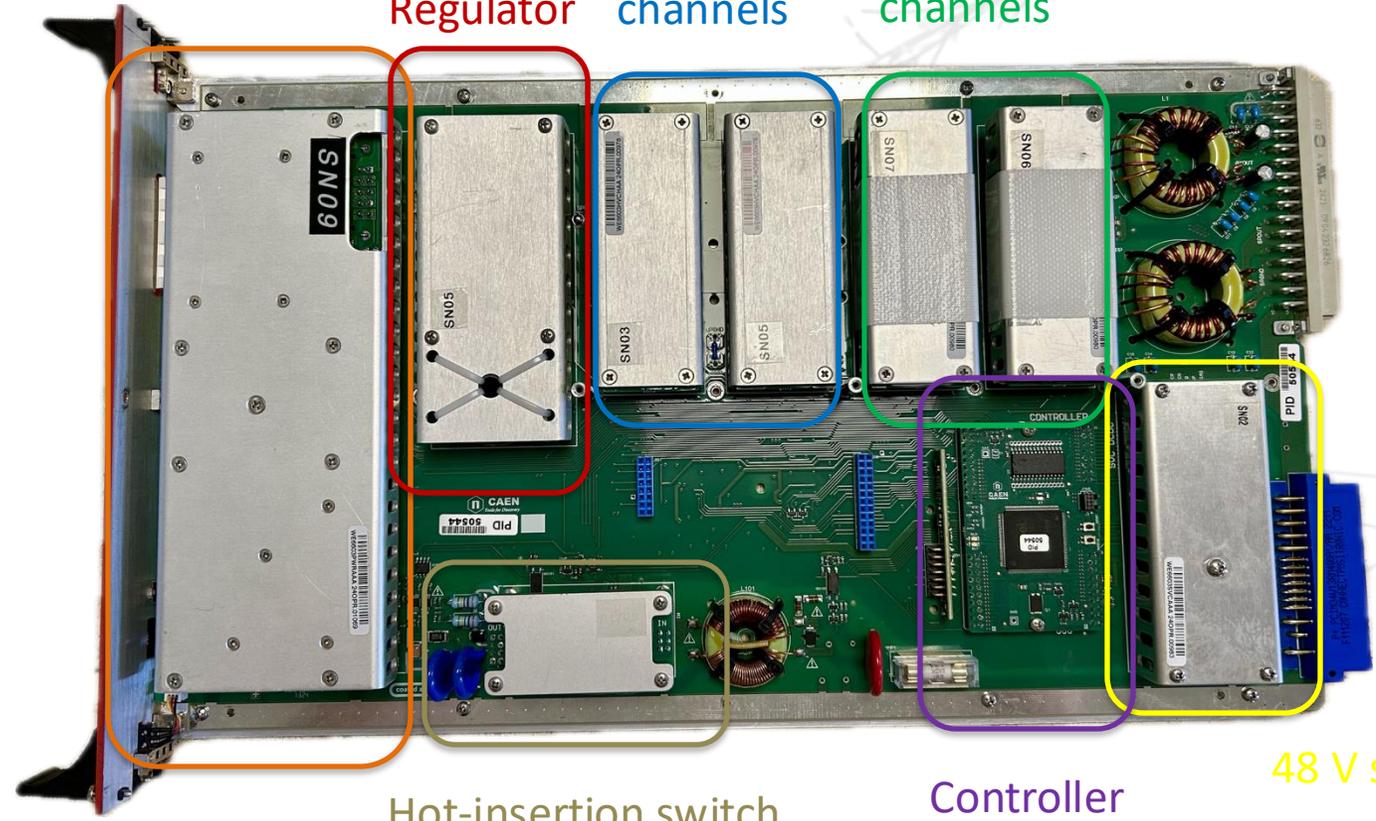


Main DC-DC

Current Regulator

HV channels

LV channels

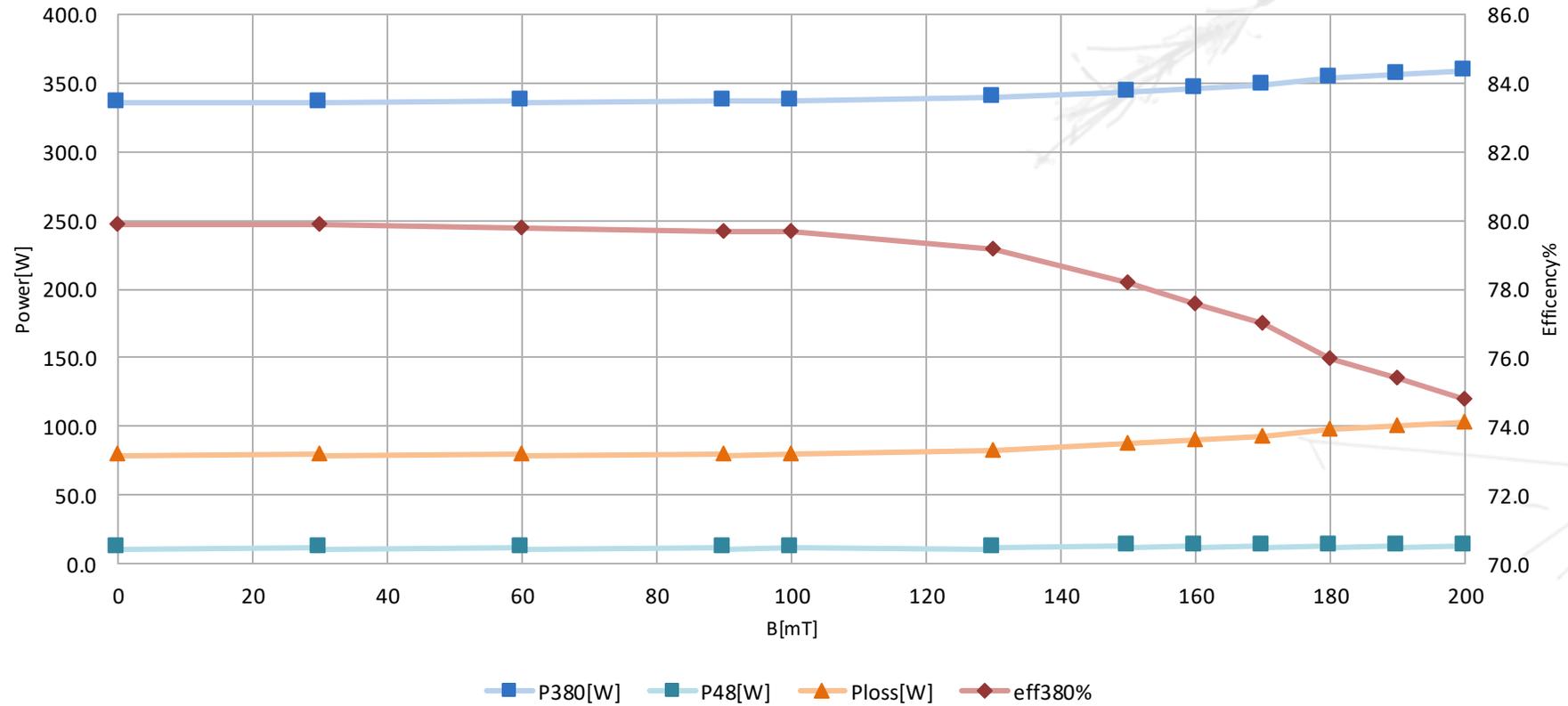


Hot-insertion switch

Controller

48 V service

A6603 performance in magnetic field



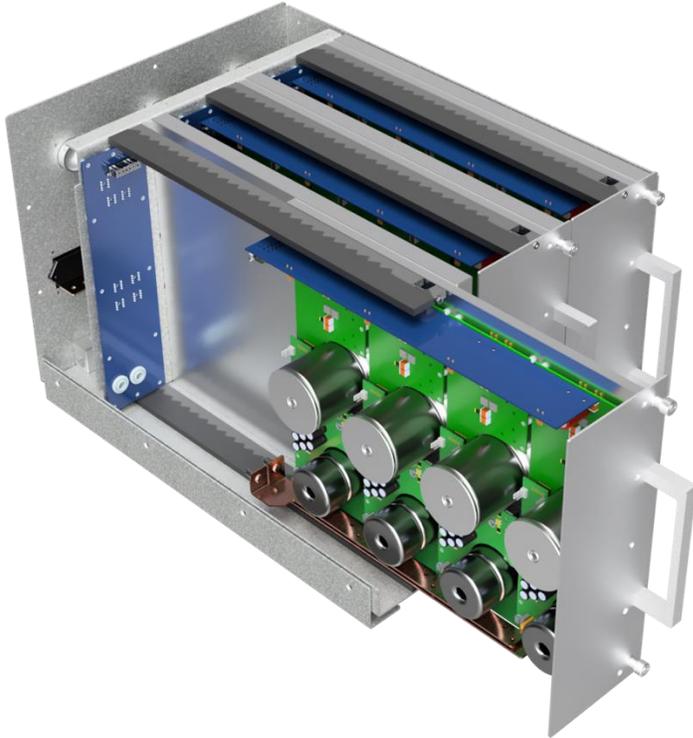


Liquid cooled EASY6000

- The EASY6001 BRIC was the first module developed to survive to the end of HL-LHC at **200 Gy** and **0.5 T** and designed for operation with **CERN DC-DC POL**
- Water cooled is a DC-DC converter from 300 V to 10 V capable of delivering more than 1.6 kW in a small format (20 x 20 x 10 cm)

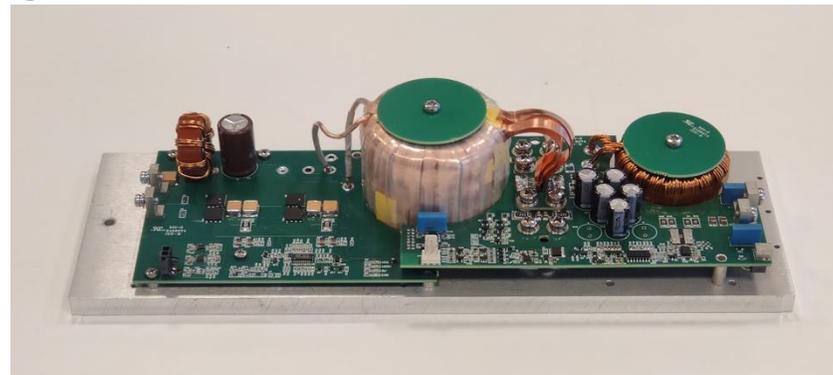
- Implementation for ATLAS-NSW and ATLAS-HGTD (4 BRIC modules in a crate)

EASY6010



- The EASY6010 is build on the EASY6001 experience pushing the magnetic field resilience to **0.6 T**.
- Redundant 3+1 channels bord to ensure smooth operations.
- Water cooled
- DC-DC converter from 300 V to 48 V capable of delivering more than 7.2 kW

- Implementation for ATLAS-LAr (3 boards in a crate)

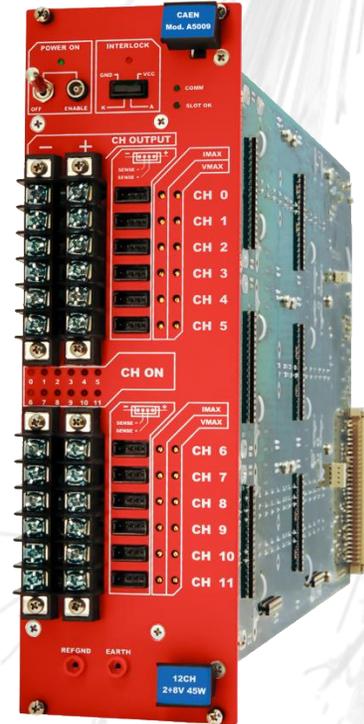
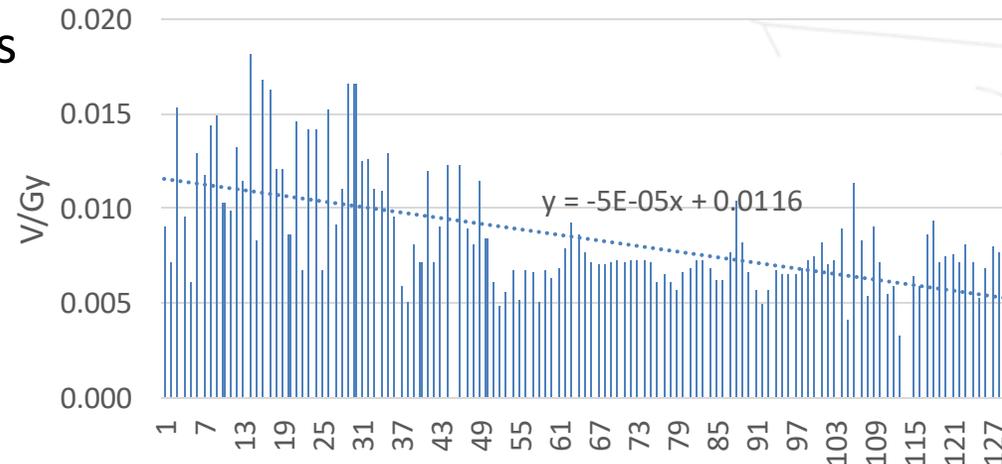


The new EASY3000 -> EASY5000



- Old EASY3000 modules are being re-designed for HL-LHC and other 20+ years of operations.
- Increased radiation hardness
- Faster communication
- Better performance and improved flexibility
 - Higher channel density
 - Parallelizable channels
 - Better efficacy
 - More diagnostics

Dependance of TID of the V_{th}

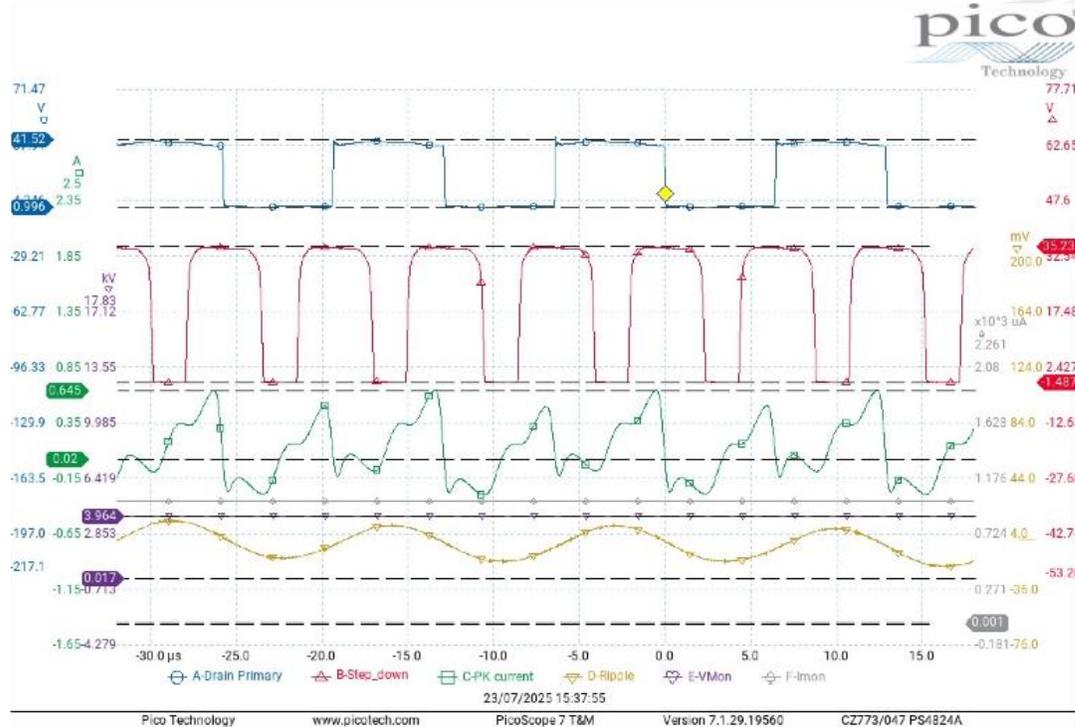


A5001 and A5540



High-channels density LV board

32 channels 5 V – 1 W each



High-Voltage board

We are designing a 16 channels configurable HV board able to deliver 4 kV and 1 mA per channels.

It has been tested up to 0.5 T (plot on the left taken at 0.2 T).

It is configurable to be individual and/or common floating, according to users' needs.



EASY family control

- Control of the EASY board is done via the branch controllers (A1676, A1660 and R6060)
- 48 V service is used to ensure safety and control of the power supplies
- All boards can be controlled by the GECO SW
- WinCC and OPC are supported as well as EPICS

Conclusion

The new EASY family is being rolled out, before the start of HL-LHC we expect all R&D to be completed.

Many new features will be available to users and the radiation resilience improved.

The portfolio will be expanded in both voltage range and power range, with custom solutions as well.

Thank you