

# Radiation Tests on the complete system of the instrumentation electronics for the LHC Cryogenics at the CNGS test facility

**Evangelia Gousiou** CERN TE CRG

# Outline

- Overview of the Cryogenic Instrumentation Electronics
- Radiation tolerance strategy
- CNGS Test Facility
- Test Setup
- Test Results
- Conclusions

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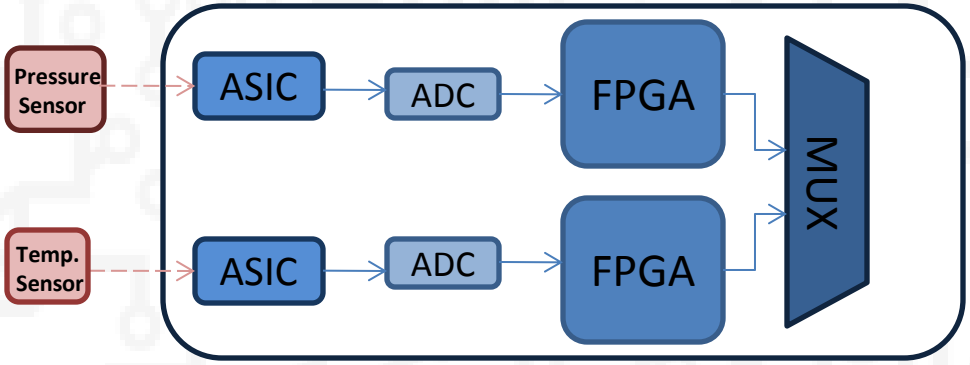
# The Cryogenic Instrumentation Electronics

- ~10.000 electronic boards assembled in ~800 crates, all around the LHC tunnel and in “protected areas”.
  - **Conditioners:** measure temperature, pressure, He level
  - **Actuators:** AC and DC electrical heaters
- All electronics will be subject to **radiation** (ionizing, non-ionizing dose and SEE).
- Manufactured mainly with **COTS** that have been prequalified, since space or military technologies were incompatible with the project budget.

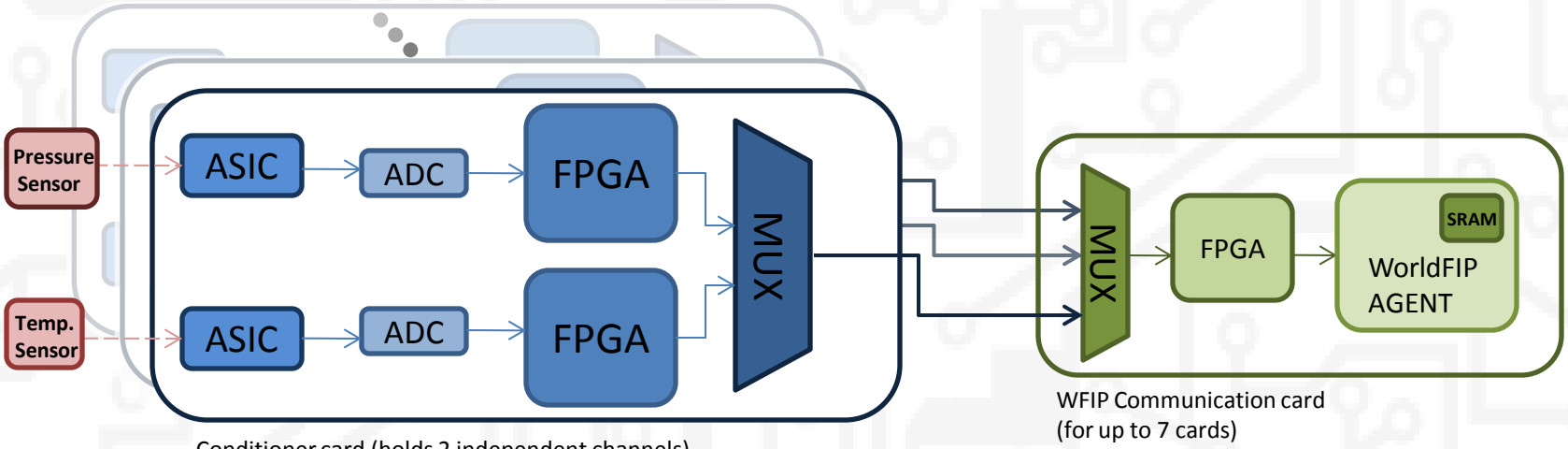
  ->-> **Replacements** foreseen during maintenance campaigns.

# Conditioner Channels Architecture




Conditioner card (holds 2 independent channels)

# Conditioner Channels Architecture



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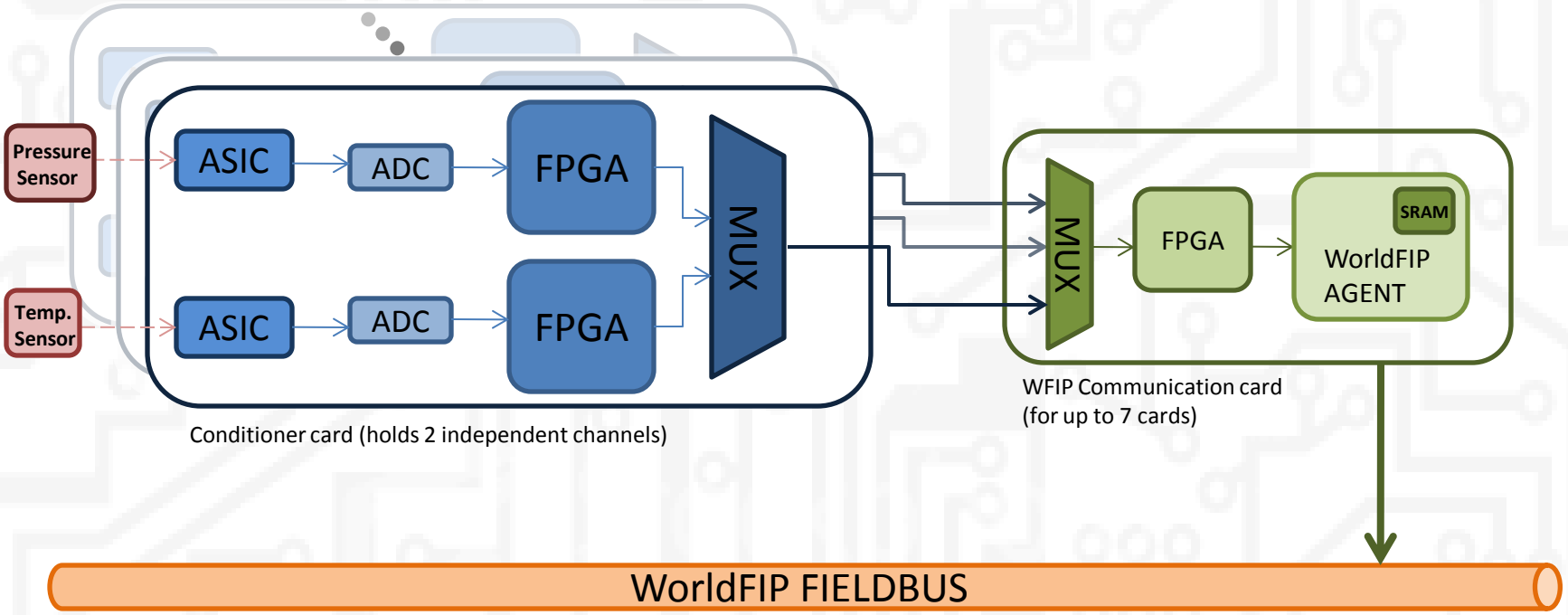

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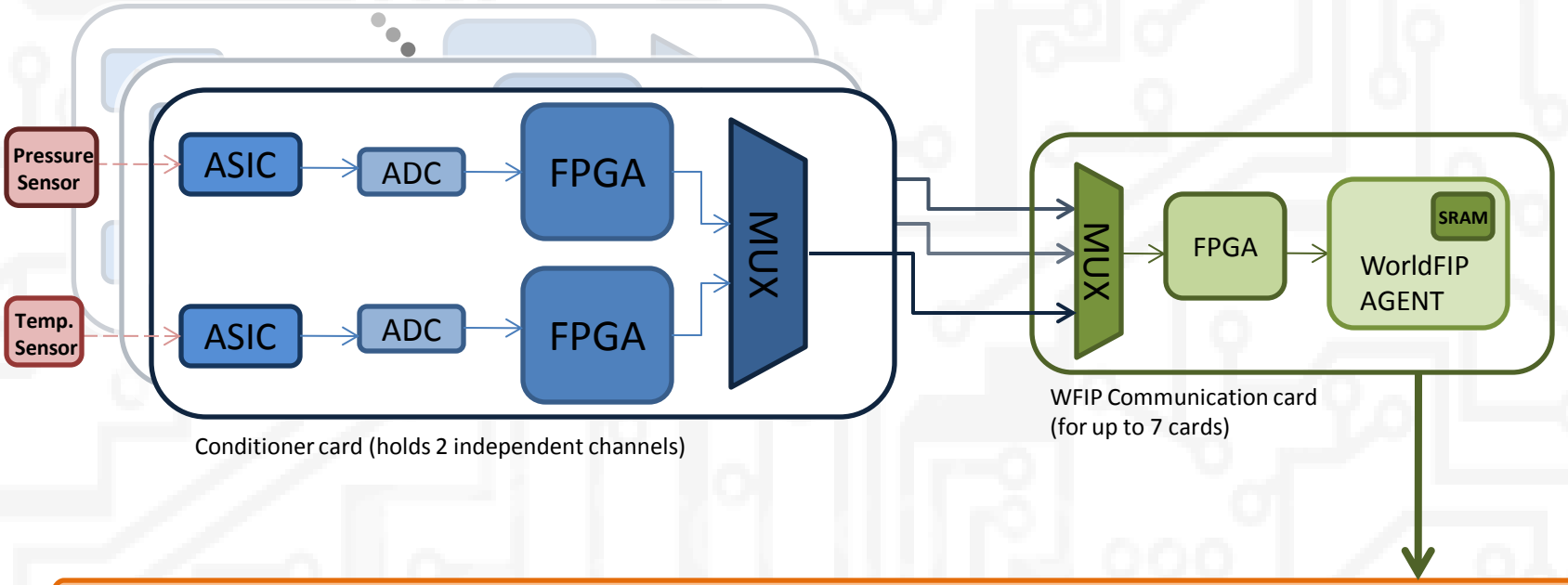


Features for high accuracy

- Continuously auto-calibrated system:
  - Comparison with a **reference** on each measurement for **gain drift** correction.
  - **Voltage polarity inversion** on each measurement for **offset** correction.
  - Excitation **current inversion** for compensation of **thermocouple effects.**

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# Radiation tolerance strategy

## Components Selection

- **Rad-hard** ASIC, Voltage Regulator developed at CERN
- **Anti-fuse** FPGA
- WorldFIP agent using signal **transformer** rather than optical insulators
- Radiation **tests** on COTS in dedicated test facilities

# Radiation tolerance strategy

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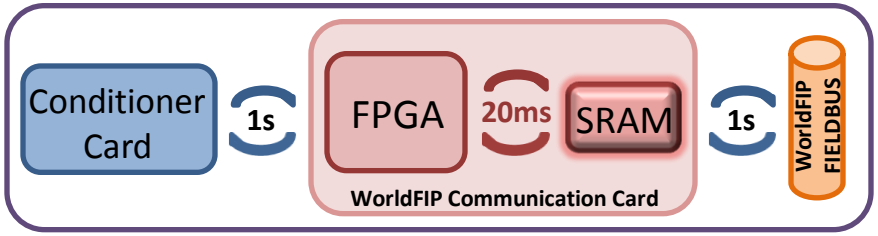
## Mitigation Techniques

- Triple module **redundancy** on FPGA logic
- Frequent **refreshment** of WorldFIP agent's SRAM memory to reduce error probability




- **Overdesign** of power supplies and thermal dissipators

# Radiation Test Campaigns

## LHC Tunnel Electronics

- **Tests** in dedicated test facilities for all the components (ITN-Portugal, UCL-Belgium, PSI-Switzerland, CERN-Switzerland).

## Protected Areas Electronics

- Radiation levels **underestimated**

-> -> Electronics **not designed** to stand radiation.

## The test campaign at CNGS aims at

Validating the performance of the **complete systems for both cases** (tunnel and protected areas).

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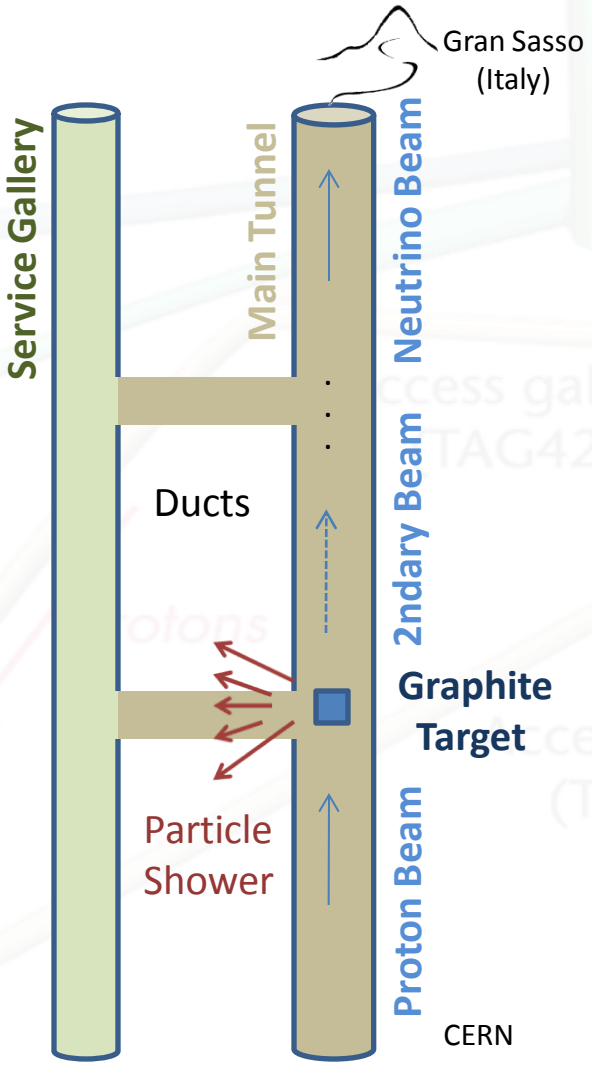
# Why CNGS?

- Tests of complete **systems** (crates)
- Exposure to **LHC-like** radiation field
- Good **knowledge** of radiation levels from simulations and real time monitoring
- **Free** of charge!

# The CNGS Test Facility



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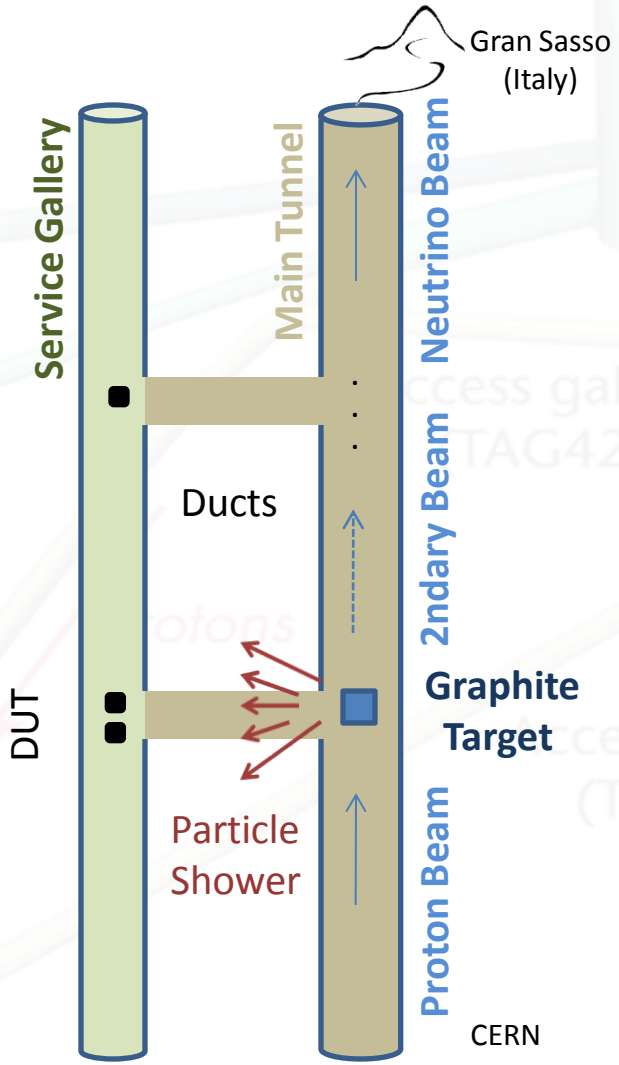

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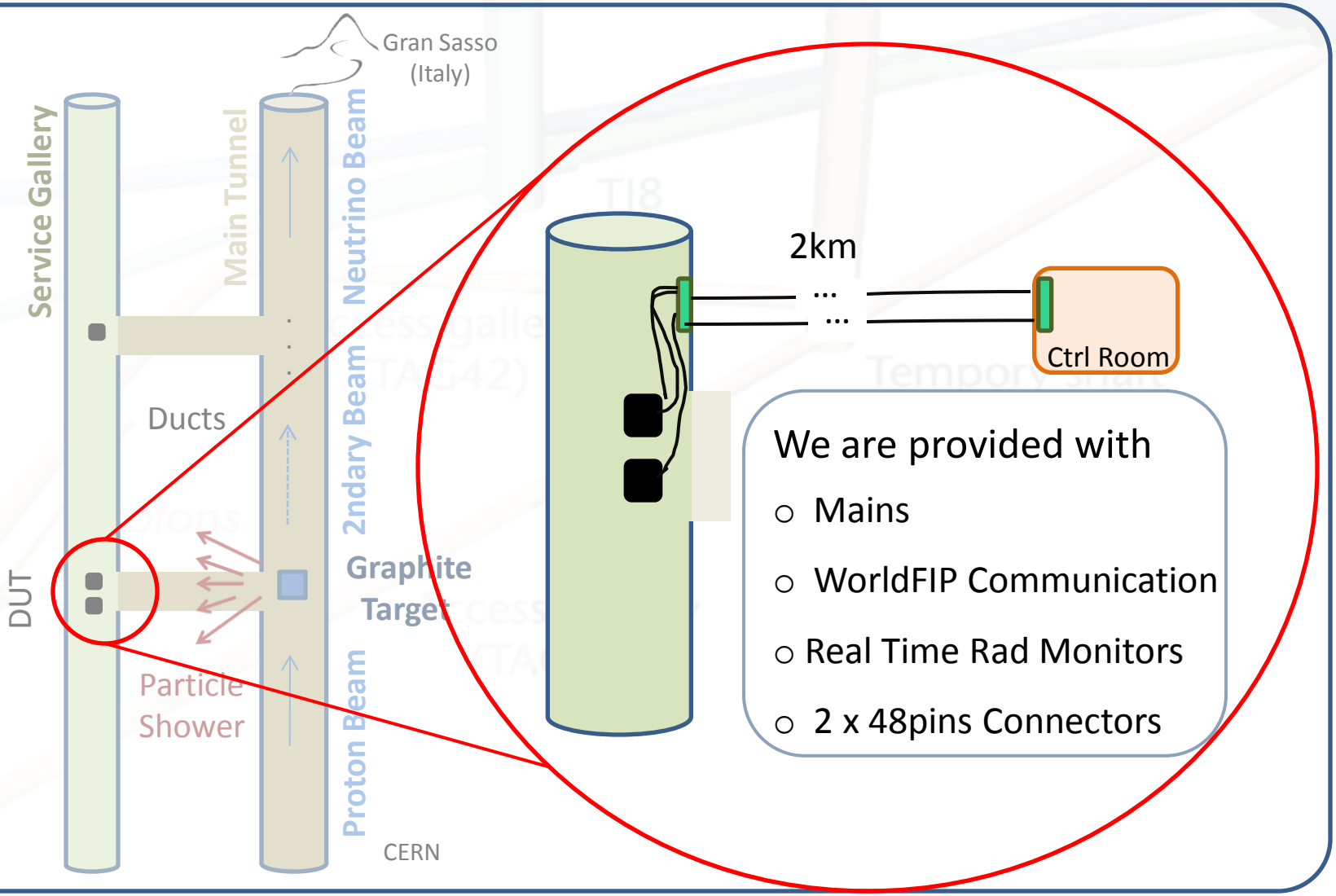

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# Equipment to Test

- 2 Cryogenic Instrumentation Crates fully equipped with Conditioners, Actuators, Communications and Power Supply Cards:
  - 25 Cards (=50 channels) of LHC **tunnel** electronics
  - 8 Cards (=16 channels) of "**protected areas**" electronics

# Test Setup

- Testing **conditions**:
  - **Fixed loads** to conditioner channels
  - **Fixed set points** to actuator channels
  - 4 **thermometers** in different locations

- On line **measurements** on DUT:
  - **WorldFIP** data as in the LHC control system
  - **Current** Consumption and **Voltage** Levels

# Testing Periods

- 1 month **dry run** tests to confirm electronics and measurements reliability.

- 1.5 months at **low** dose radiation station:

| | |
|---|---|
| TID (Gy) | 18 |
| NIEL (n/ $cm^2$) | 2.6e+11 |
| >20MeV (h/ $cm^2$) | 1.3e+11 |

+

- 1.5 months at **high dose** radiation station:

| | |
|---|---|
| TID (Gy) | 105 |
| NIEL (n/ $cm^2$) | 3.6e+12 |
| >20MeV (h/ $cm^2$) | 2e+12 |

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# Protected Areas Electronics

## 1. AC Heater Actuators Overview

- **Cumulative** effects failures:

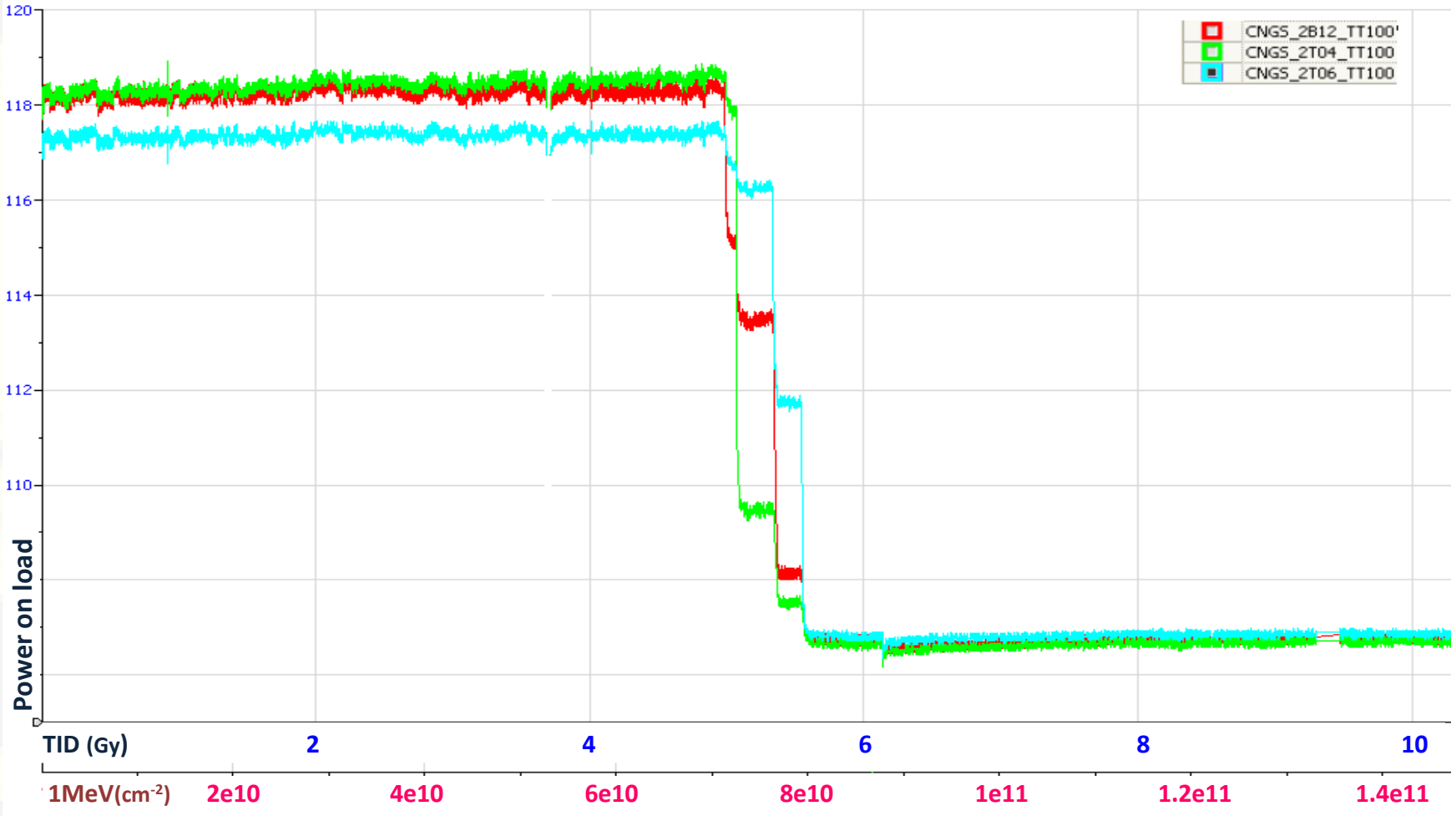
| | |
|---|---|
| TID (Gy) | 5 |
| NIEL (n/ $cm^2$) | 7e10 |
| LHC years<br>in the worst case | 0.3 |

-> Failing **component**: Solid state relay

->-> **Solutions** for the LHC: Moving of electronics, shielding of protected areas.

- Same results for 6 channels and **reproduced** in two different CNGS locations.

# Protected Areas Electronics



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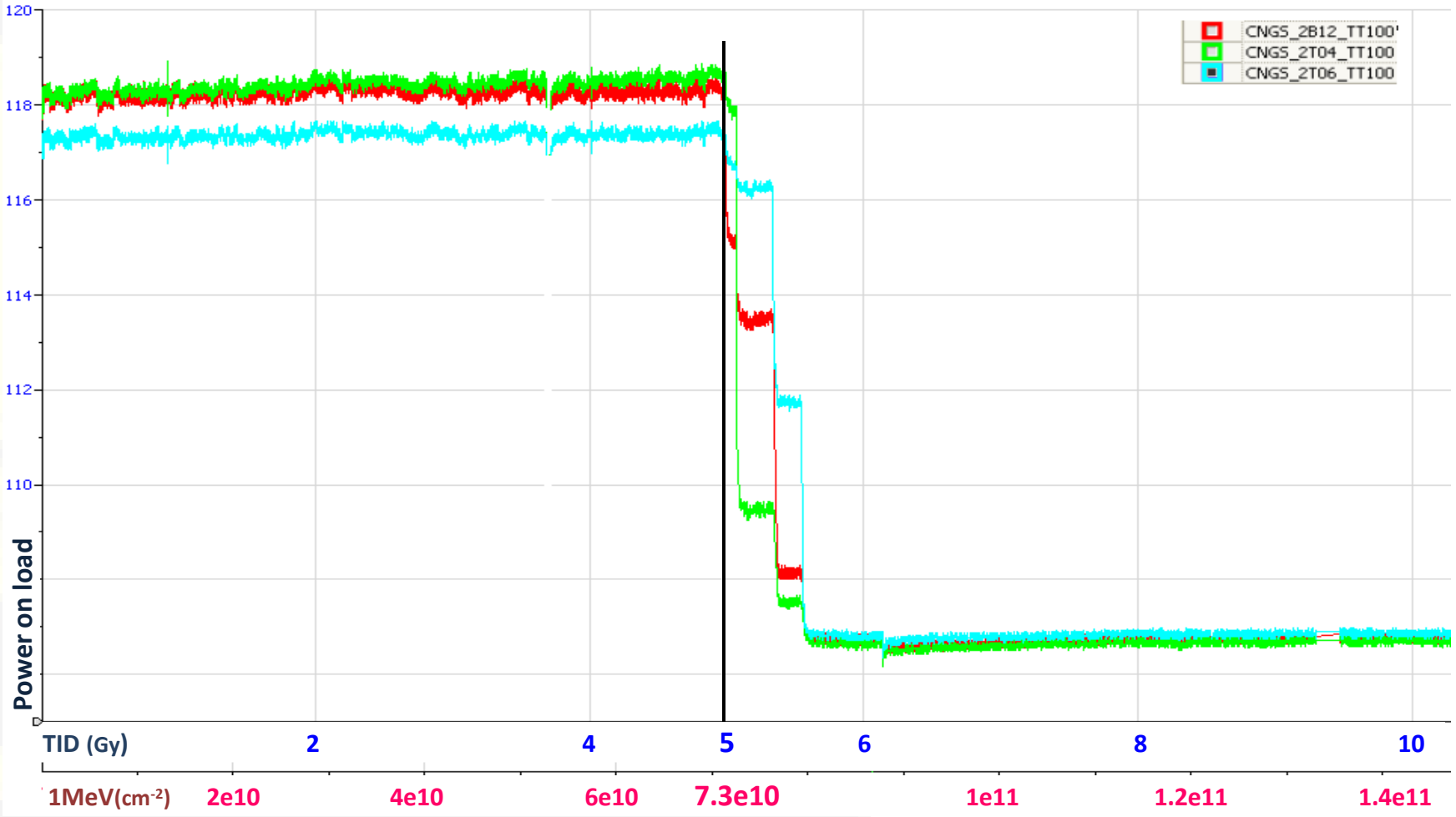
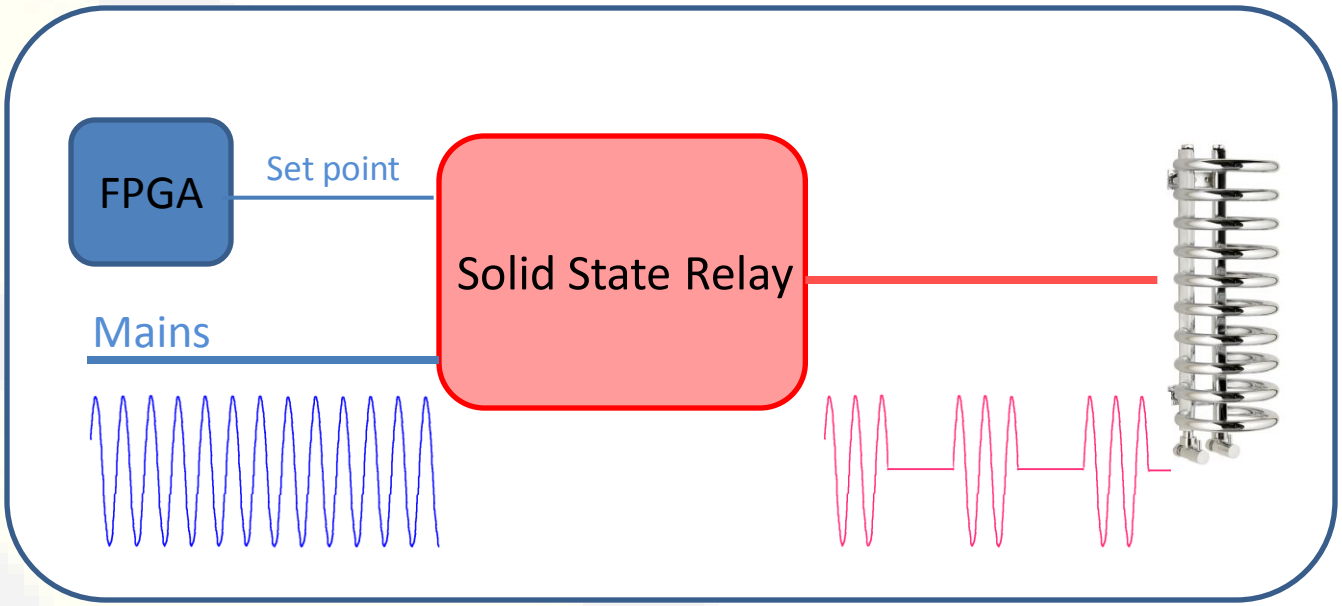


# Protected Areas Electronics

## 1. AC Heater Actuators

Failing Component



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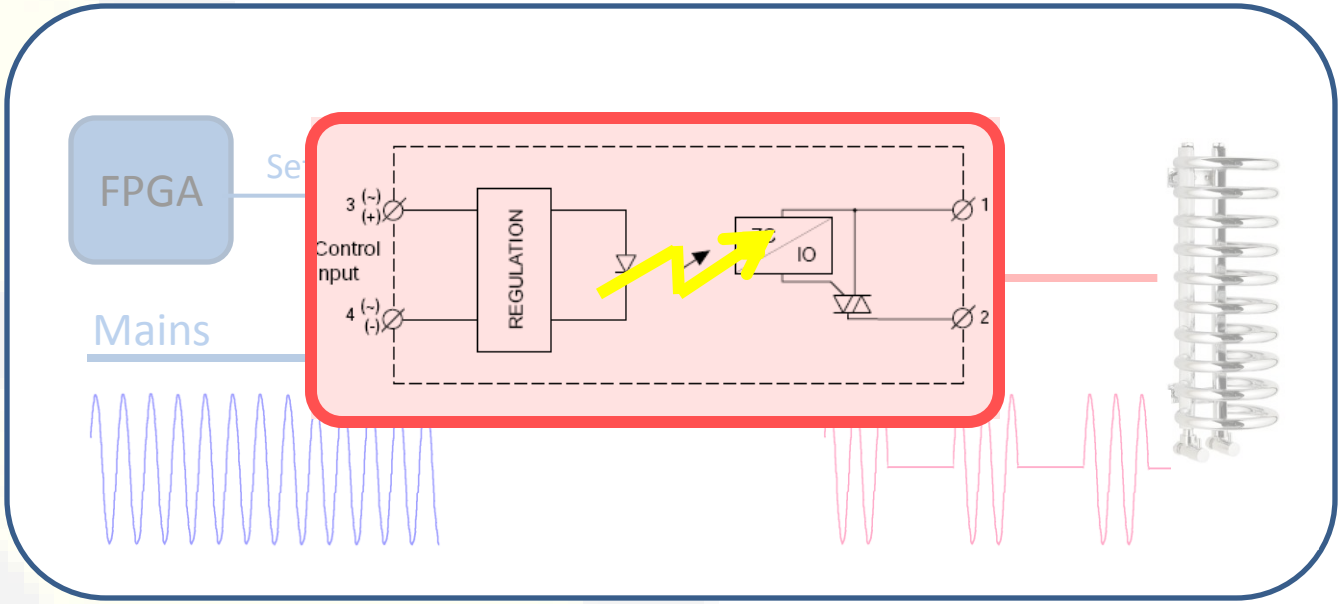


# Protected Areas Electronics

## 2. Insulated Temperature Conditioners Overview (I)

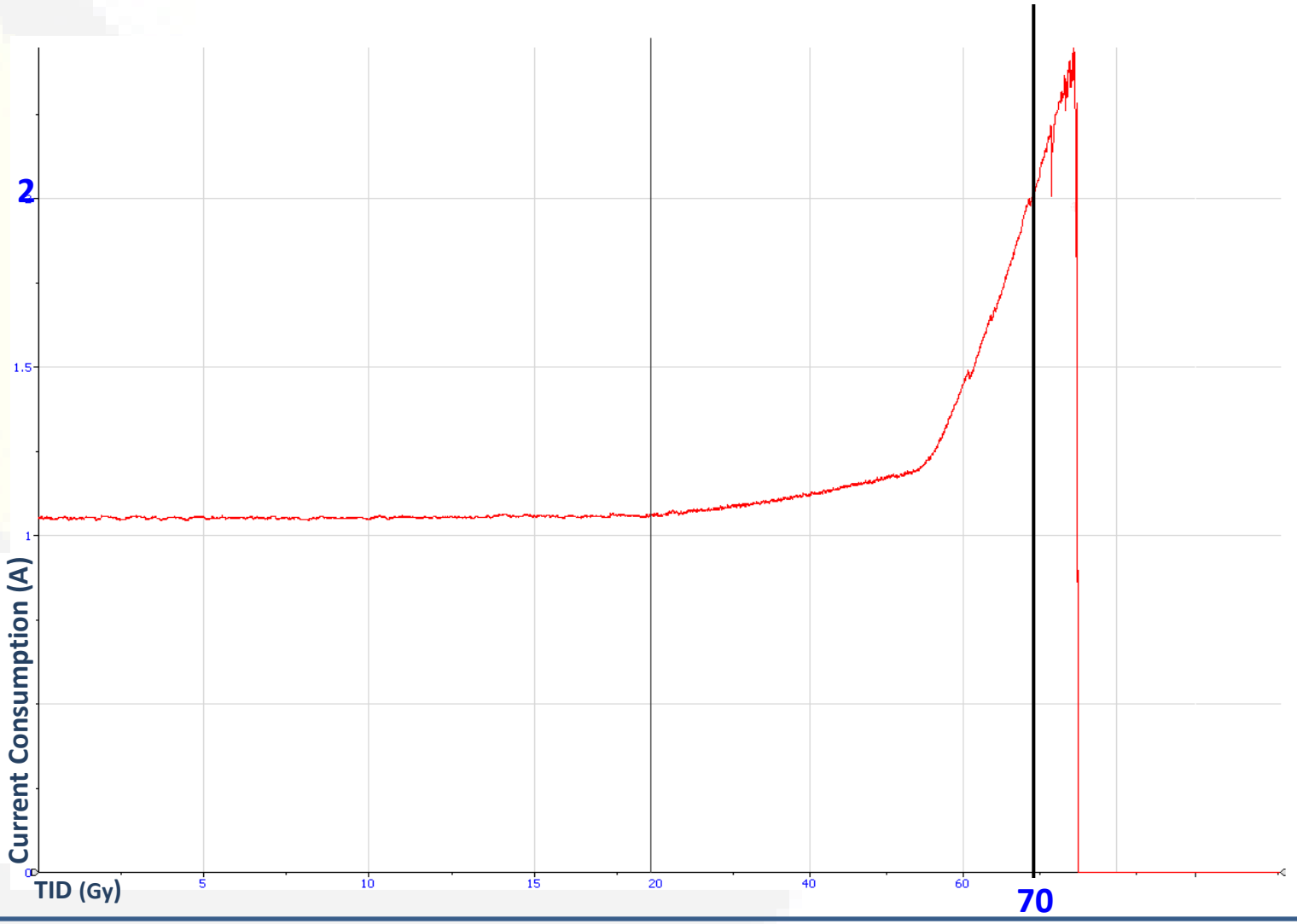
- **Cumulative** effects failures:

| | |
|---|---|
| TID (Gy) | 70 |
| NIEL (n/ $cm^2$) | 2e12 |
| LHC years<br>in the worst case | 4 |

-> Failing **component**: DC-DC converter; plans for tests in dedicated test facilities.

- Same results for 12 channels and **reproduced** in two different CNGS locations.

# Protected Areas Electronics



# Protected Areas Electronics

## 2. Insulated Temperature Conditioners Overview (2)

- **Single Event Upsets:**

| | |
|---|---|
| Cross Section (/cm2) | 2e-9 |
| LHC SEU/ hr in the worst case | 6 |

-> Failing **component**: Digital Isolator

->-> **Mitigation** Technique for LHC: soft reset automatically forced by the control system;

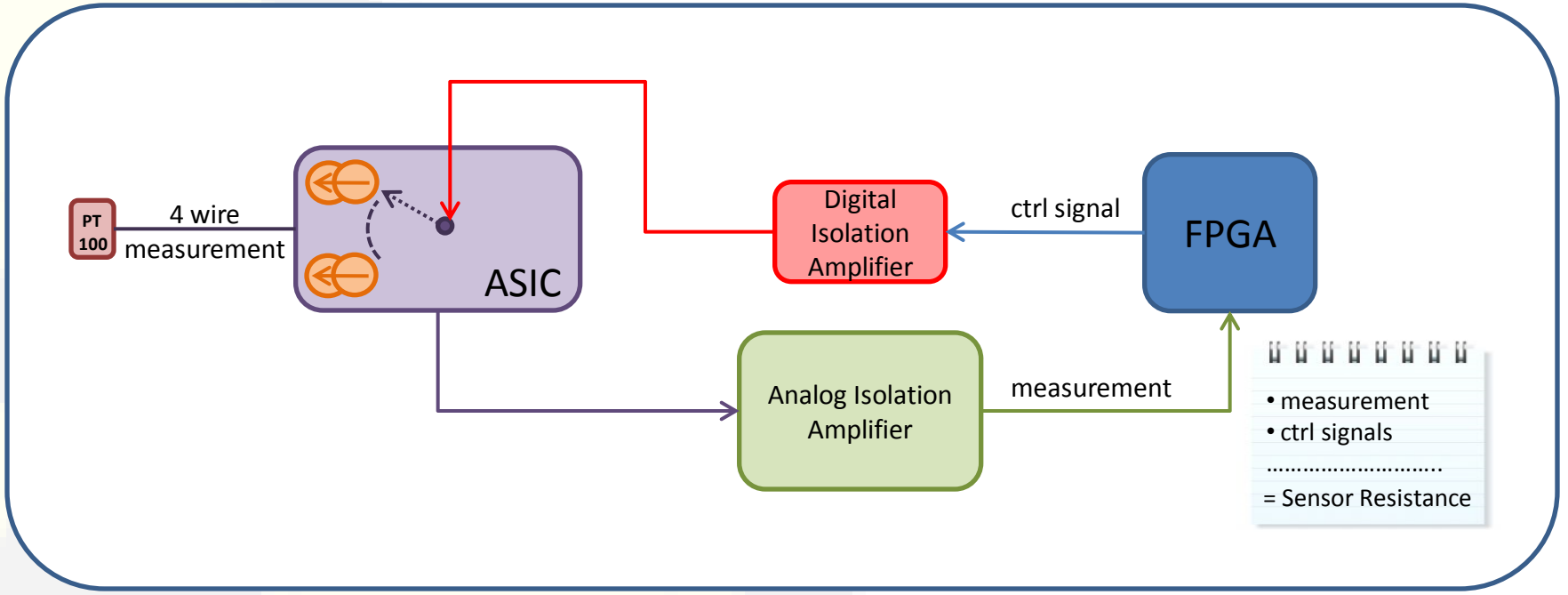
No influence on proper operation of the machine.

- Same results for 12 channels and **reproduced** in two different CNGS locations.

# Protected Areas Electronics

## 2. Insulated Temperature Conditioners

SEE occurrence



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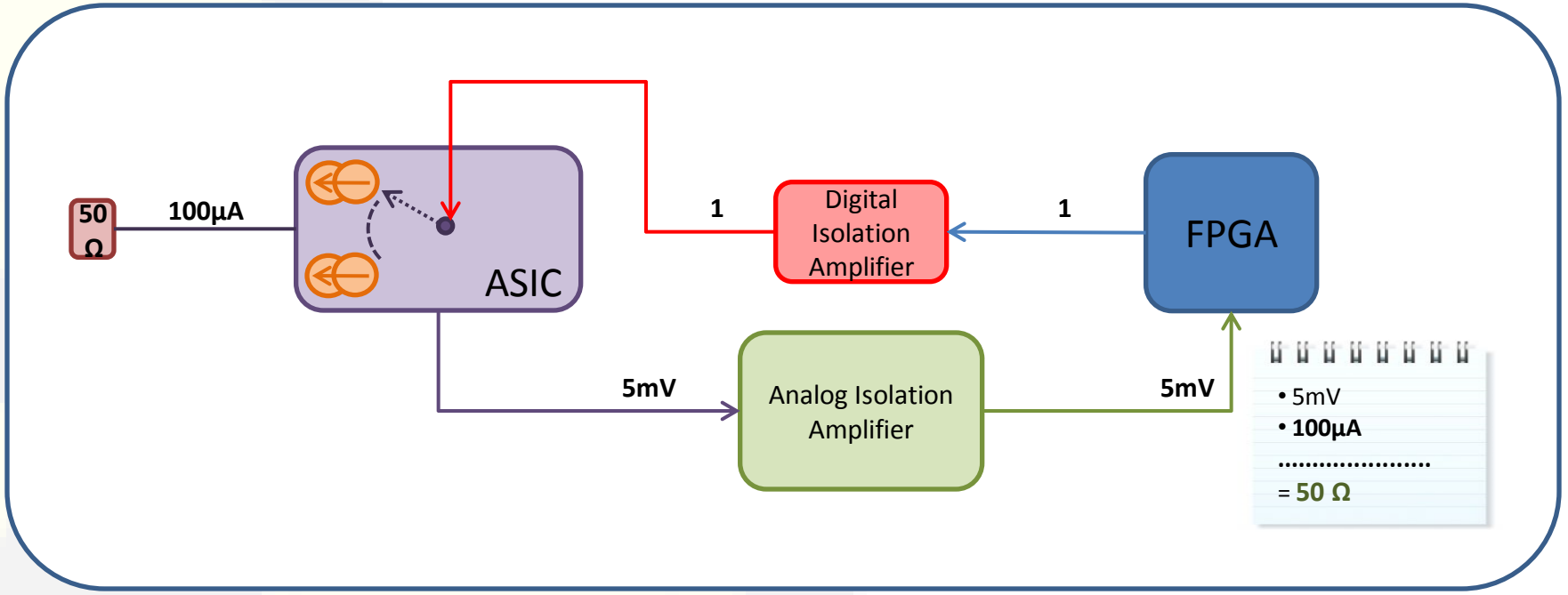

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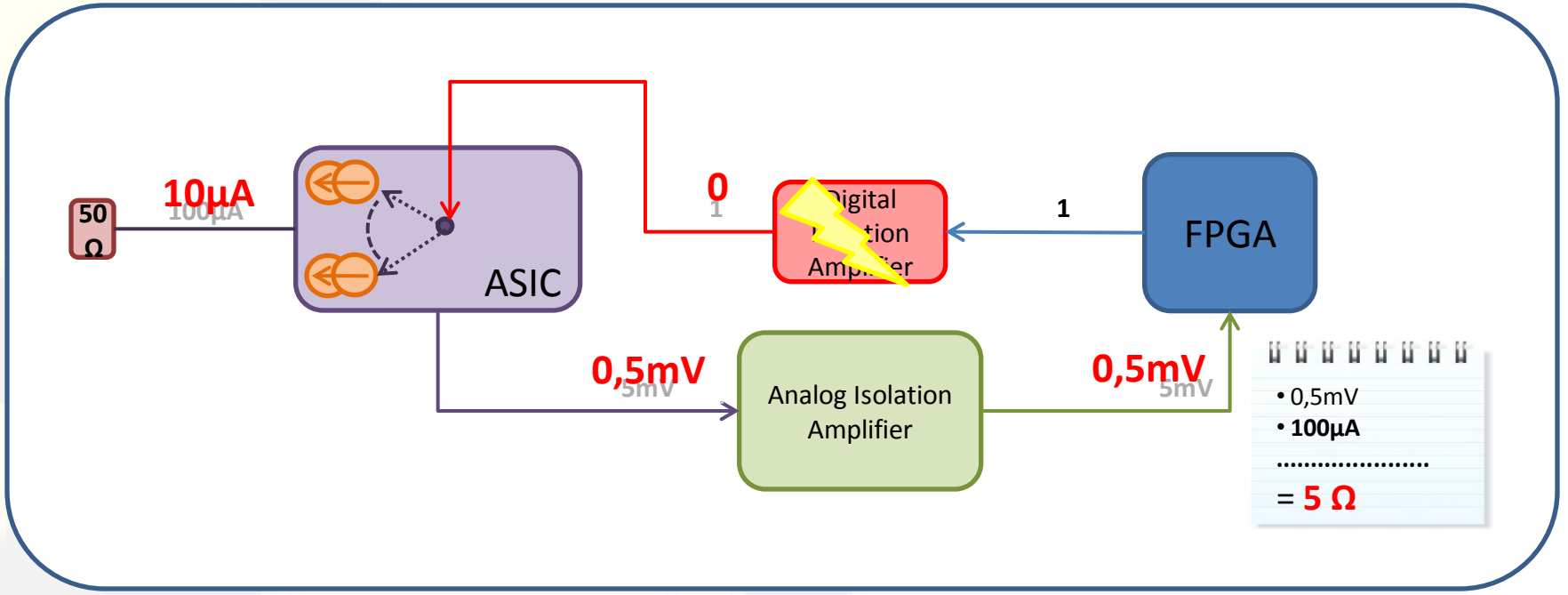



- A soft remote **Reset** brings the situation back to normal.
- Cross section calculation: $\sigma = \frac{\#SEE}{fluence>20MeV} = \frac{\#Resets}{fluence>20MeV} = 2.2e\text{-}9\ cm^{-2}$

# Tunnel Electronics Overview

- Tunnel electronics have received till now a **cumulated** dose of:

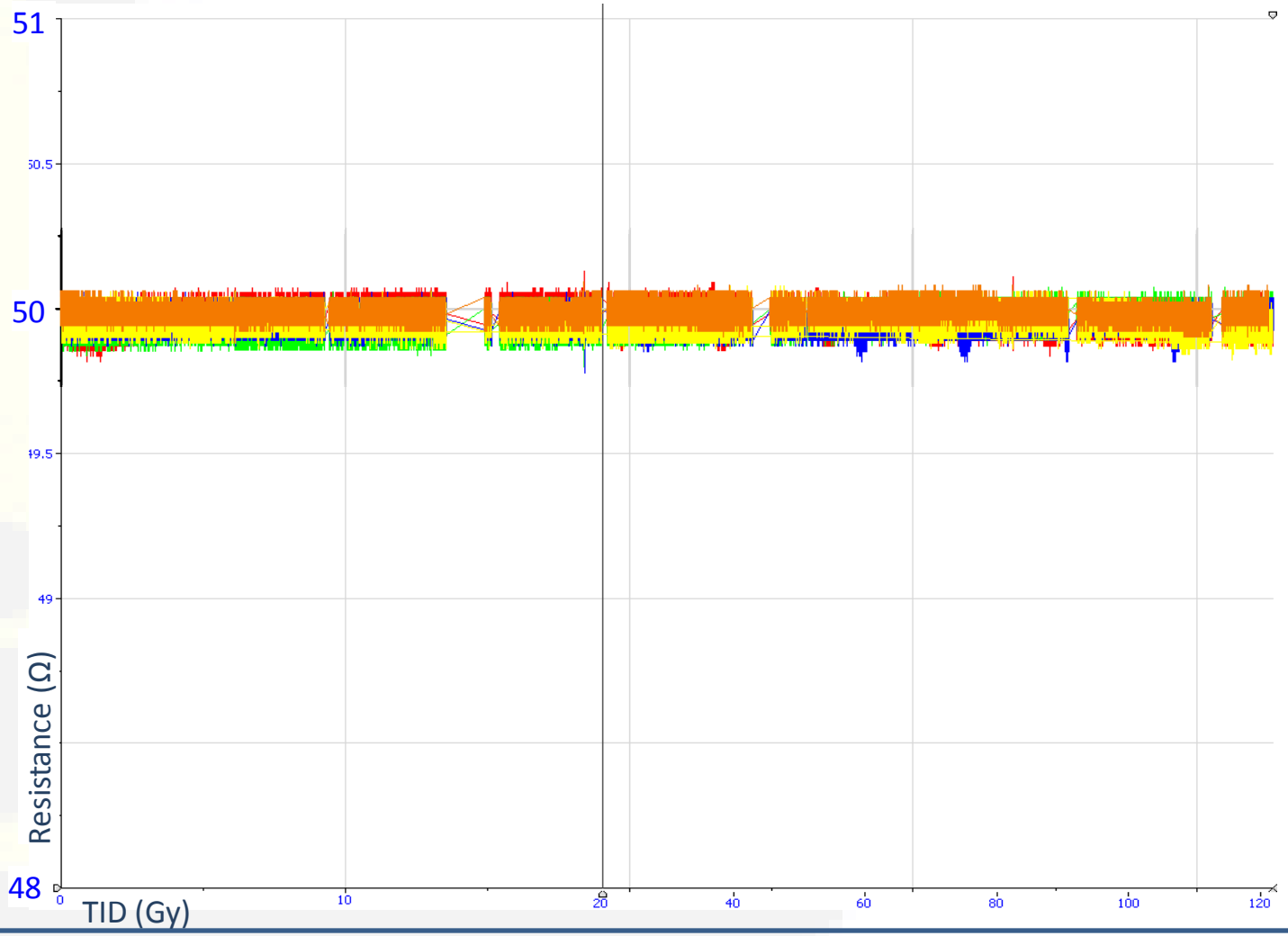
| | |
|---|---|
| TID (Gy) | ~125 |
| NIEL (n/ $cm^2$) | ~4e12 |
| LHC years<br>in 90% of the cases | >10 |

..and the tests are still **ongoing**!

- No **Single Event Errors**!

- Still **within specs** in output accuracy!

# Tunnel Electronics



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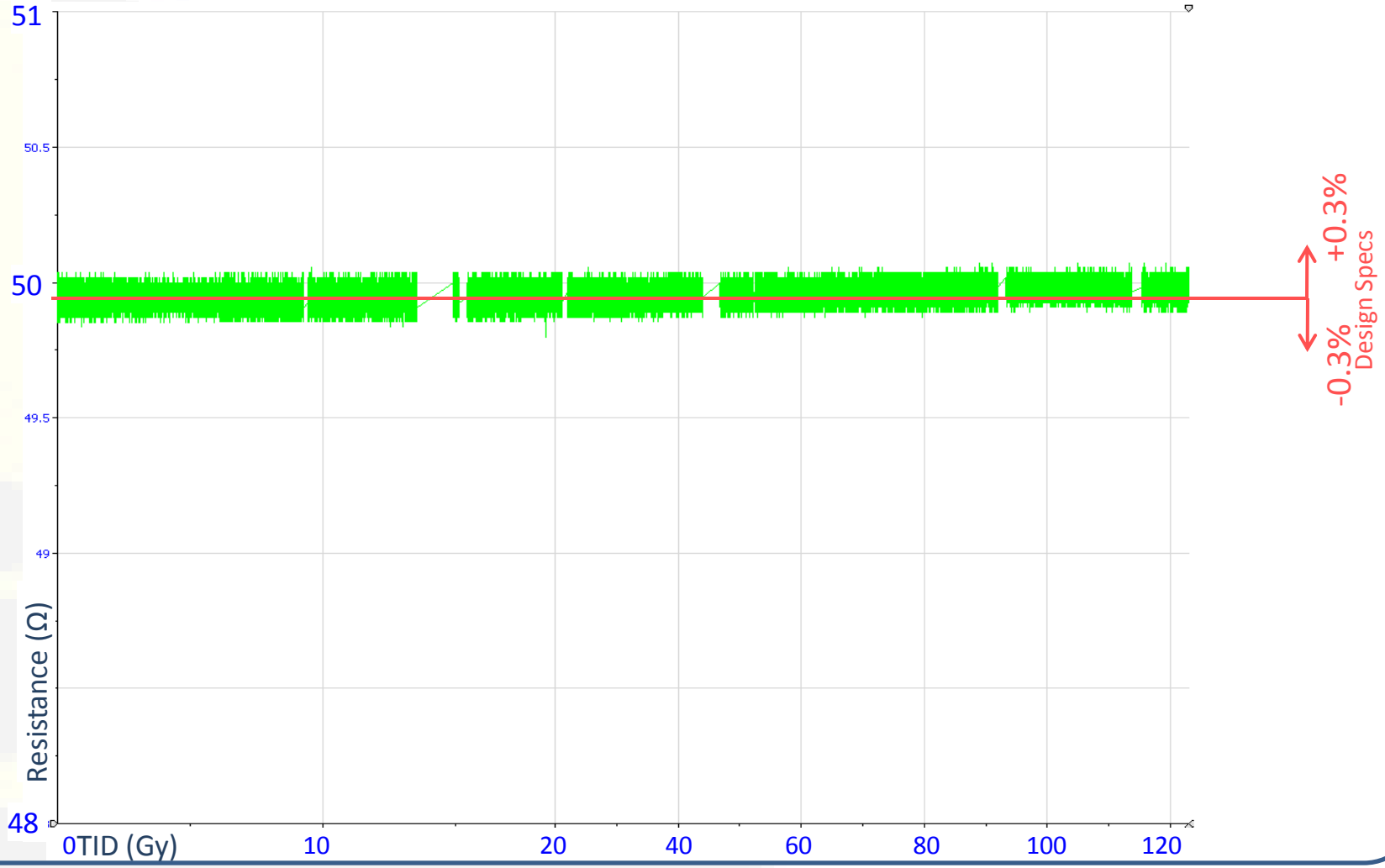

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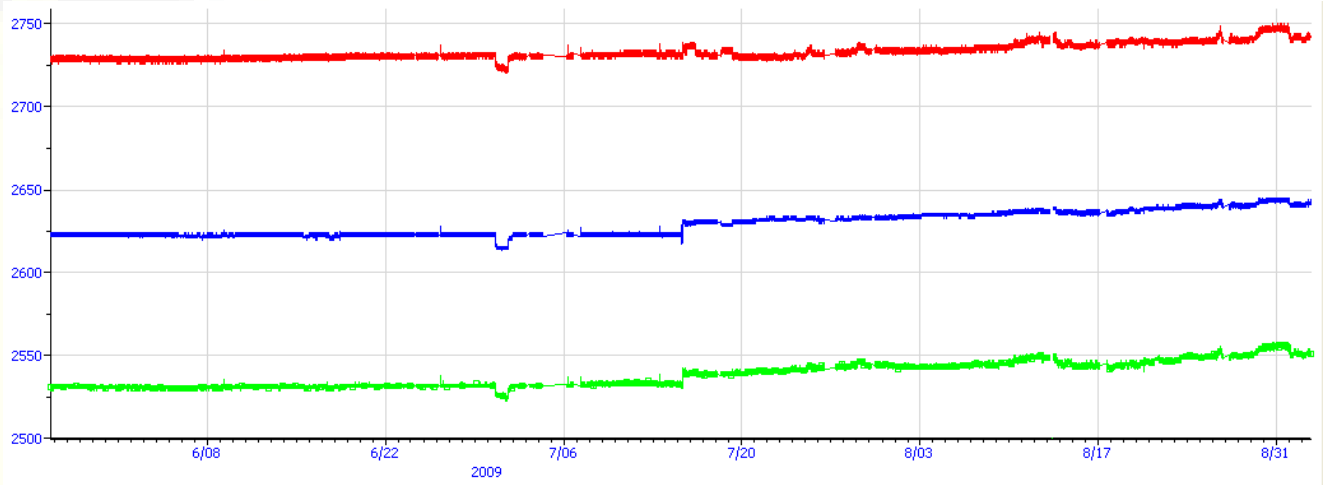
..and the tests are still **ongoing**!

- No **SEE**!
- Still **within specs** in output accuracy!
- BUT! Gain **drifts** already observed and corrected by auto calibration features.

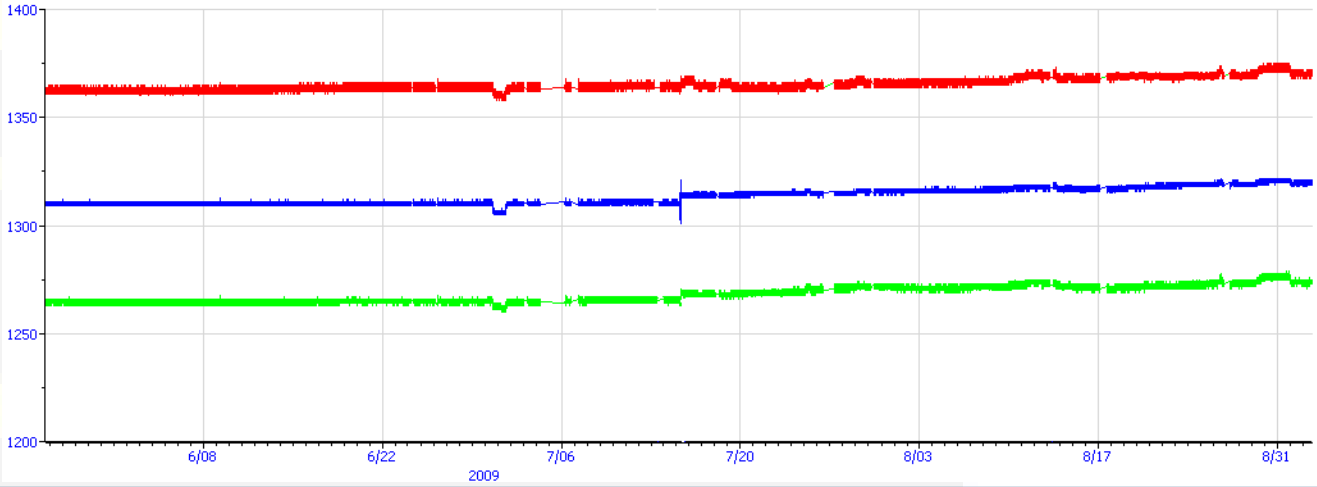
# Tunnel Electronics

Sensor Voltage




$V_{sens} = G*I*R_{sens}$

Reference Voltage

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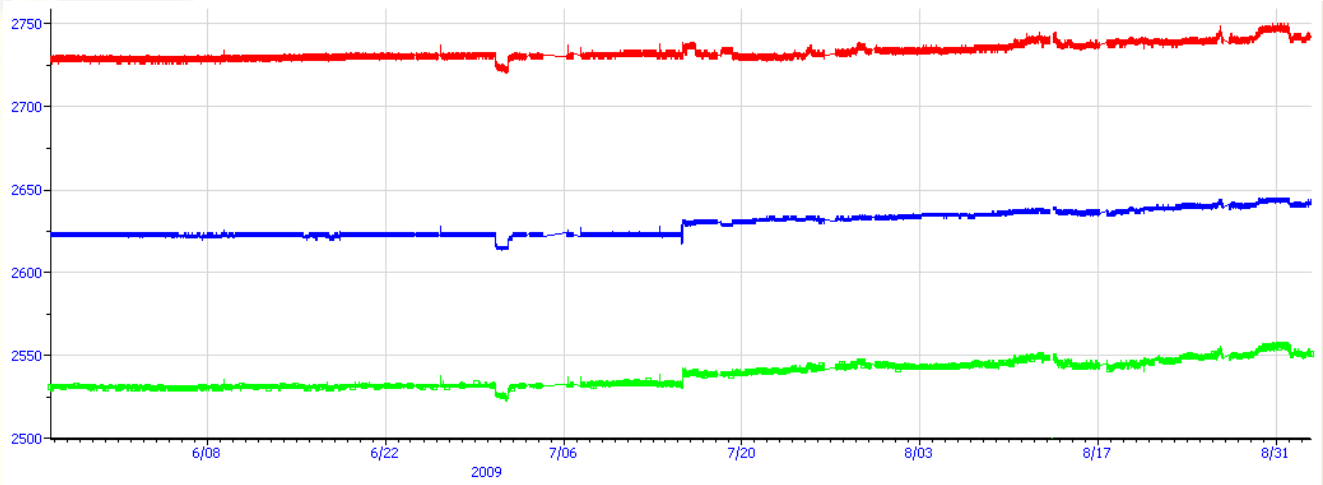


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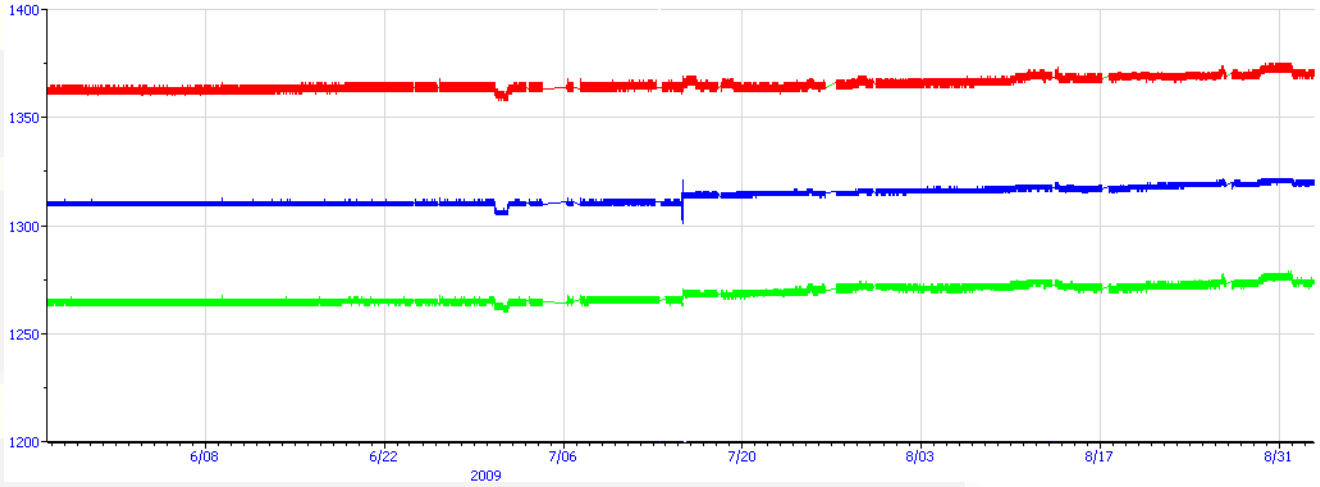


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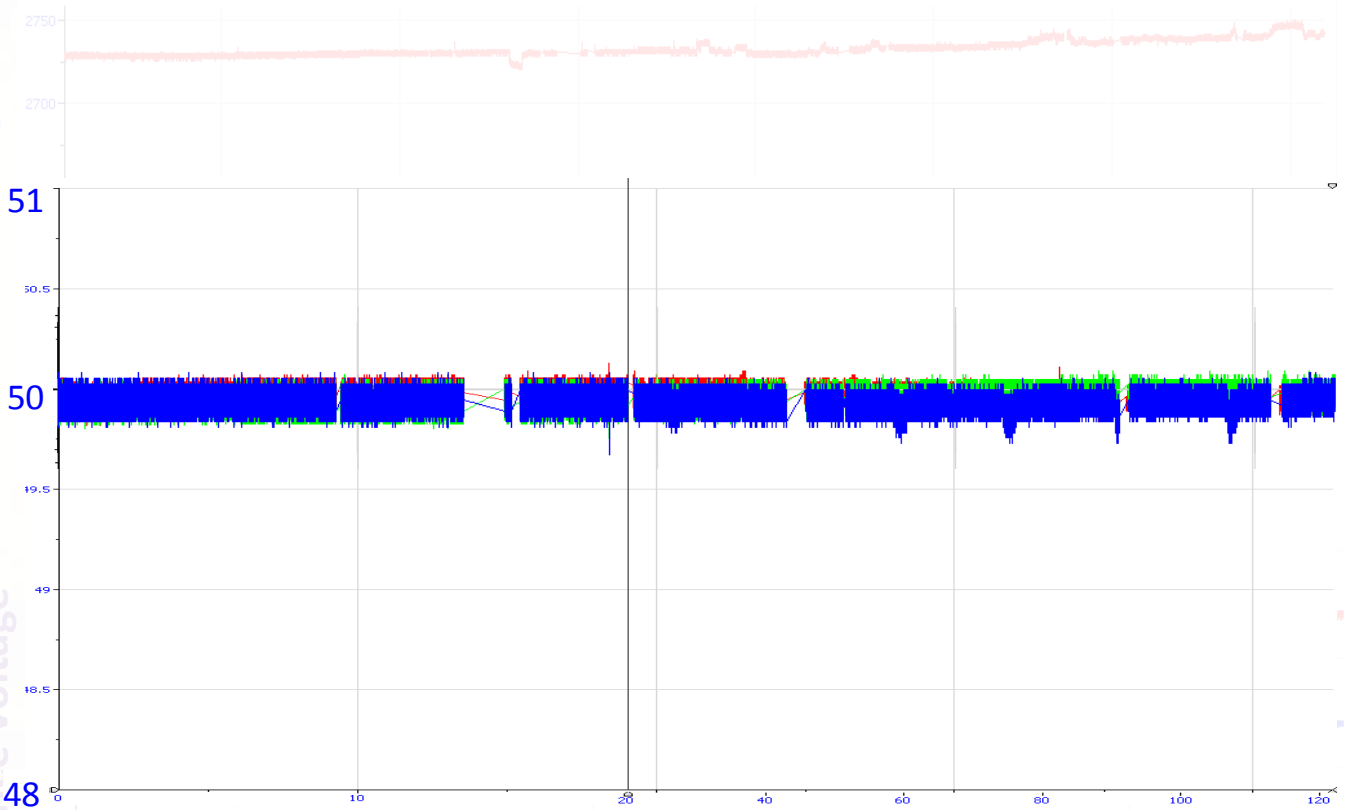


$$R_{sens} = R_{ref} \frac{V_{sen}}{V_{ref}}$$

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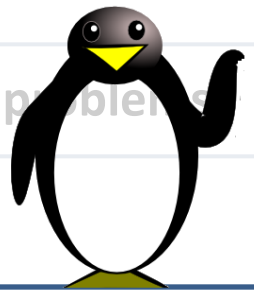
# Conclusions

- CNGS testing has provided quantitative **knowledge** about the radiation tolerance of our complete system.
- **Confirmation** of LHC tunnel electronics reliability.
- **Identification** of protected areas electronics weaknesses.
- First approach of possible **solutions**.

# Conclusions

- CNGS testing has provided valuable **knowledge** for all our electronics
- **F**
- Thank you for your attention
- **Optimism** in the case of tunnel electronics
- Multiple solutions for the protected areas electronics **p**



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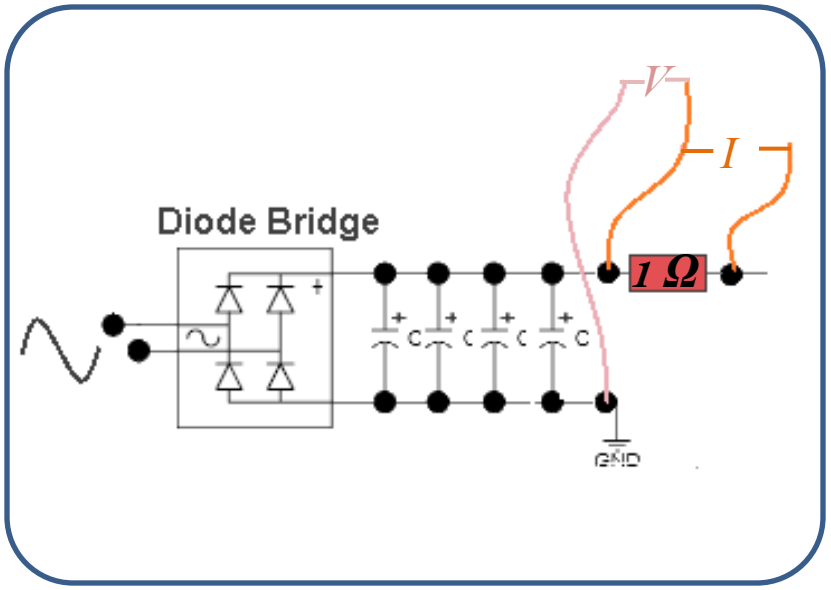
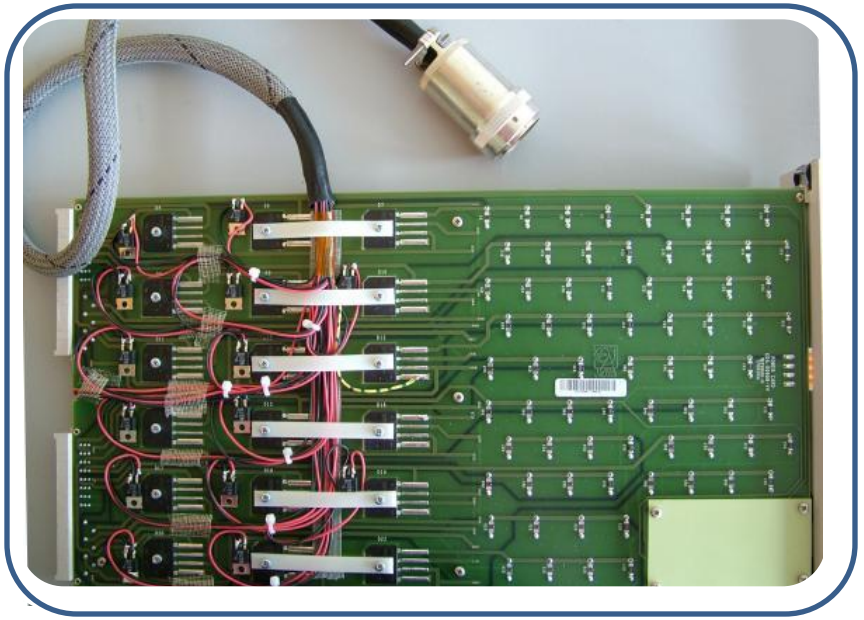
# Extras

# Voltage & Current Measurements

- In order to probe and gain access to the Current Consumption and Voltage Level signals, **modification** needed to be done on the Power Supply Card
  - The Power Supply Card receives the mains and provides channels of DC Voltage for all the Cards in a Crate
  - A 1Ω robust **resistance inserted in series** in the tracks of the Power Card



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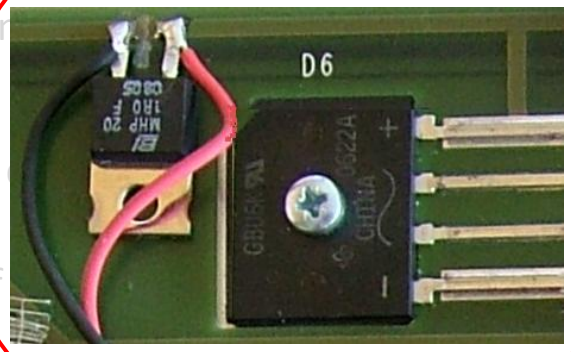


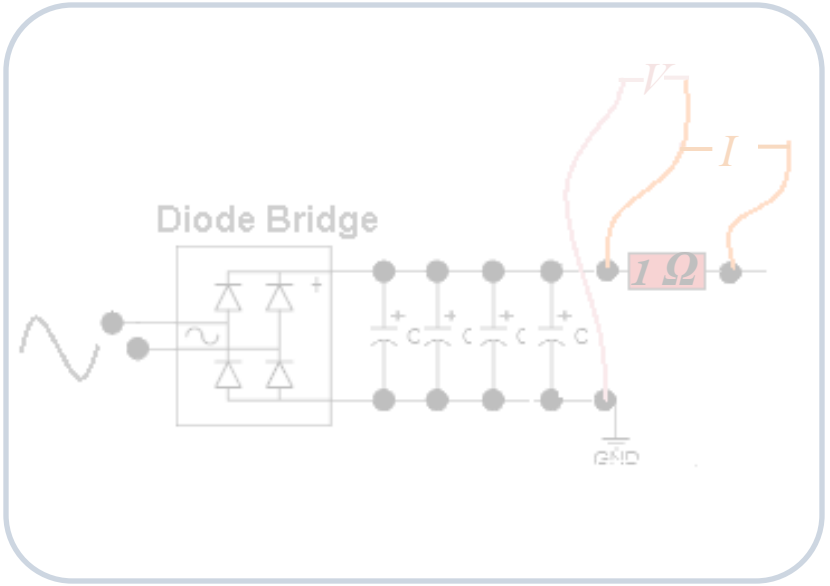


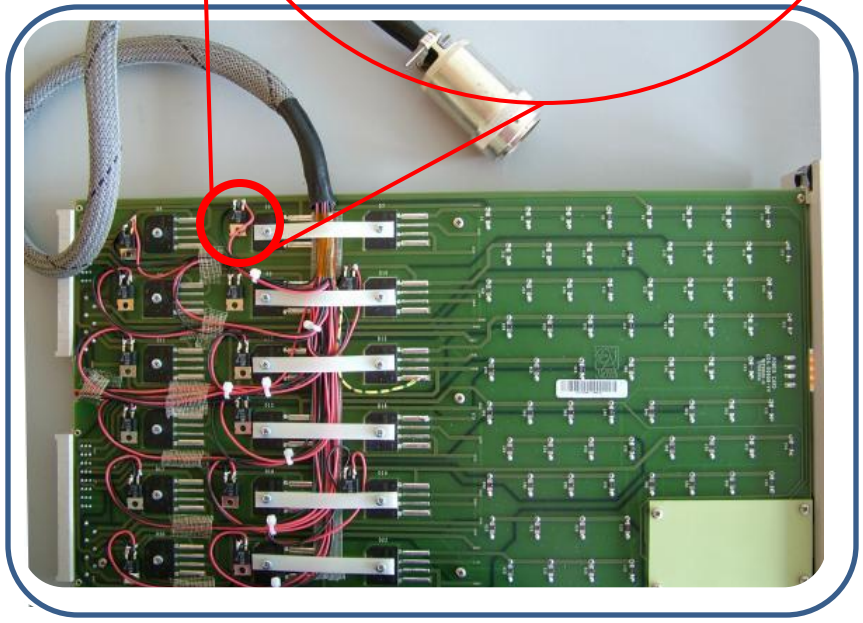

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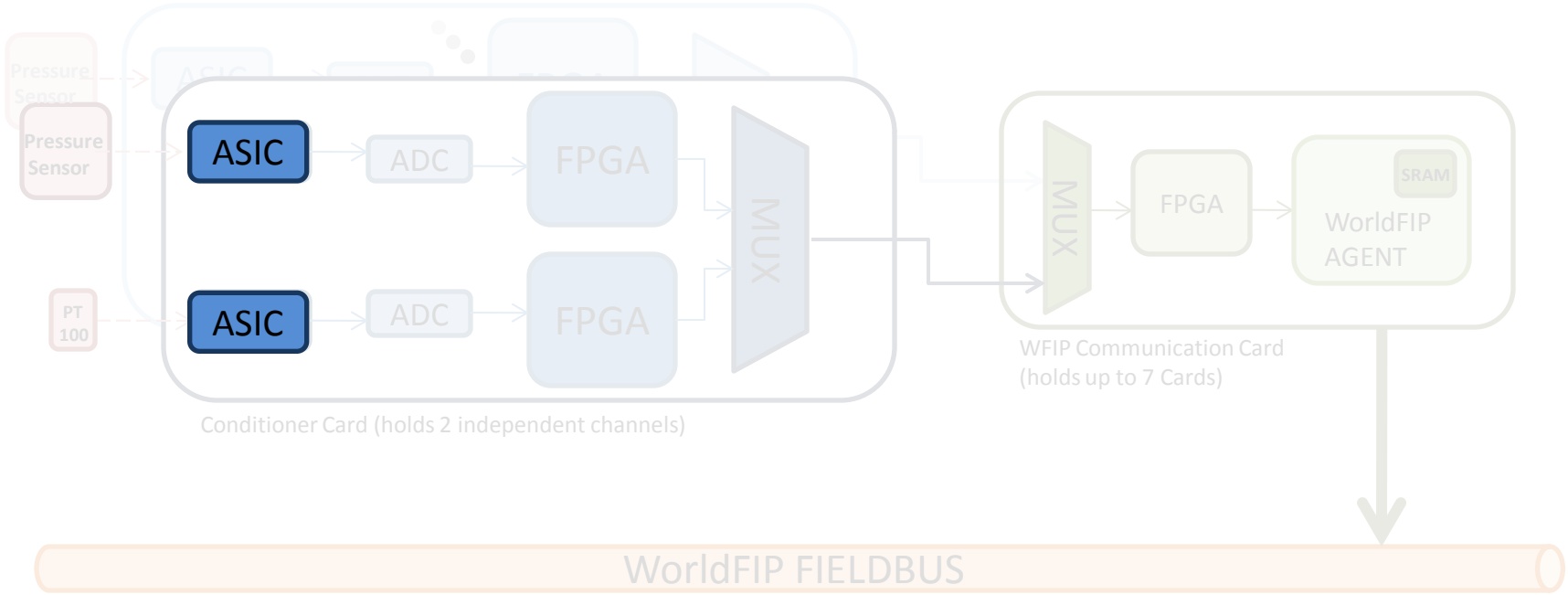


## High Accuracy main features

- Auto-calibrated System: high precision resistor measured every time a variable measurement is taken and correction of amplifier offset by amplifier input inversion as well as correction of cable TC effects by current inversion.

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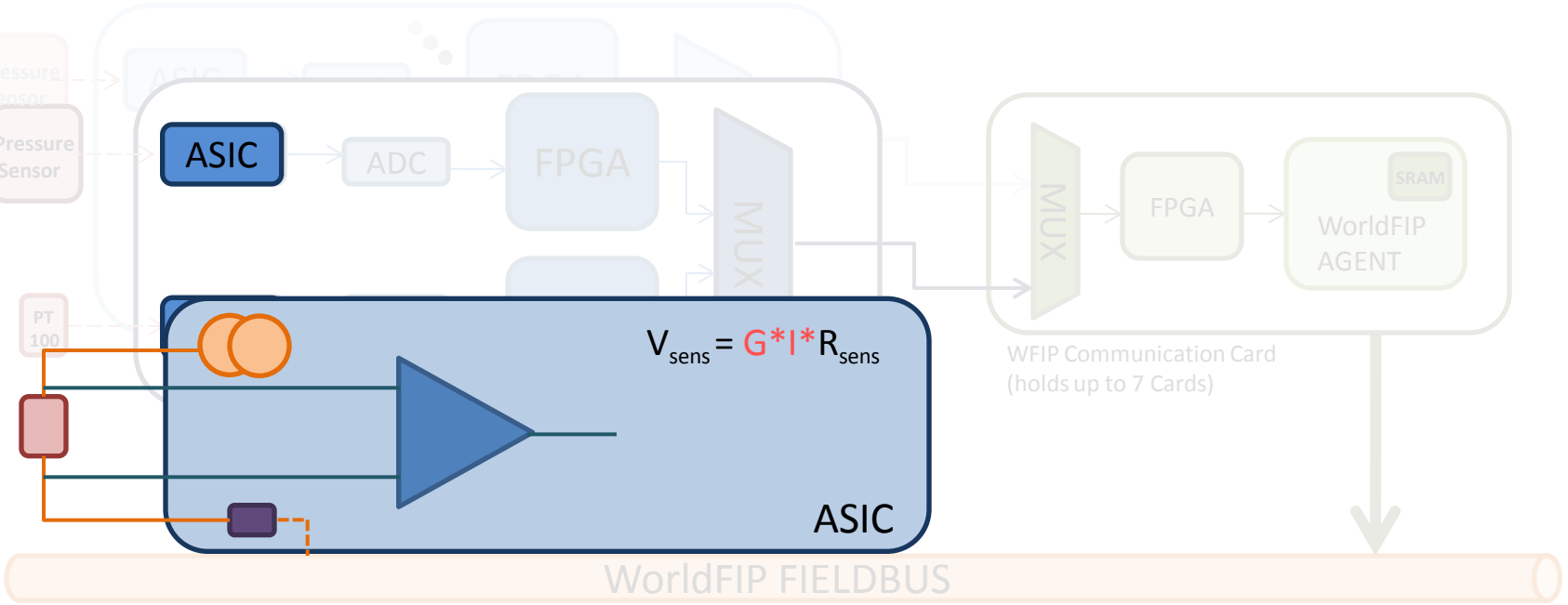


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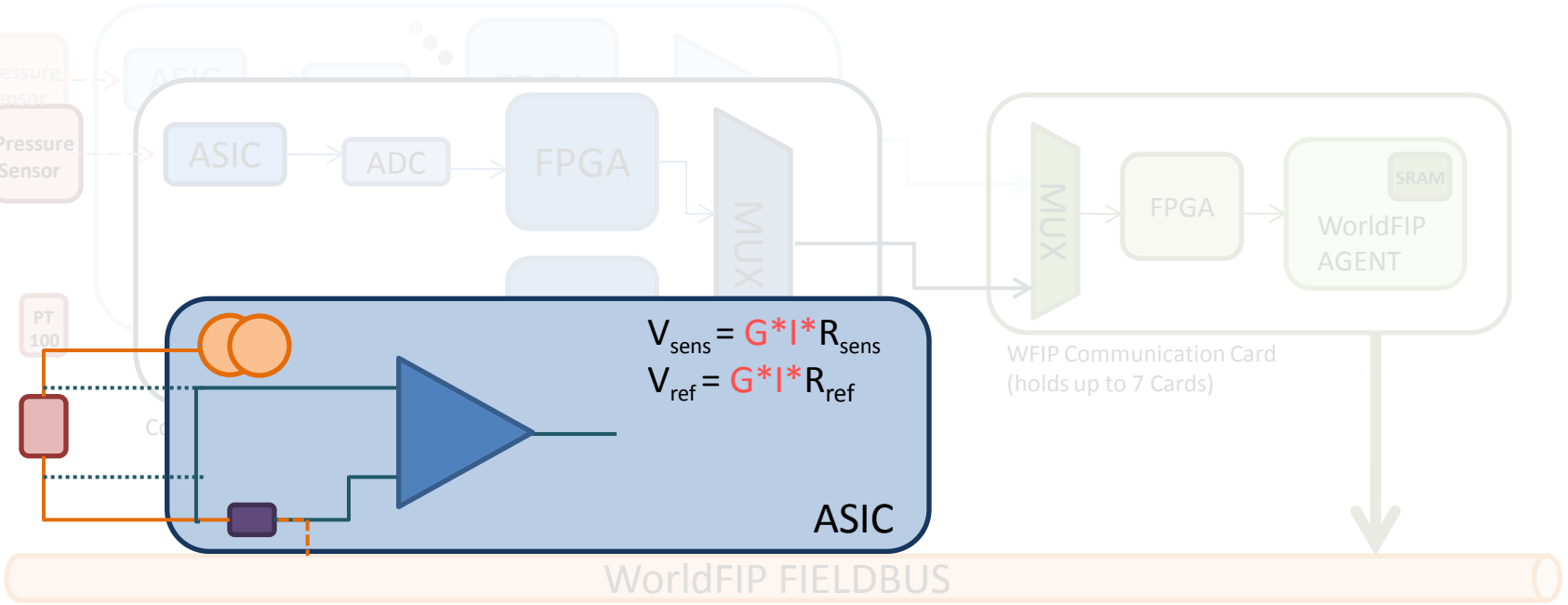


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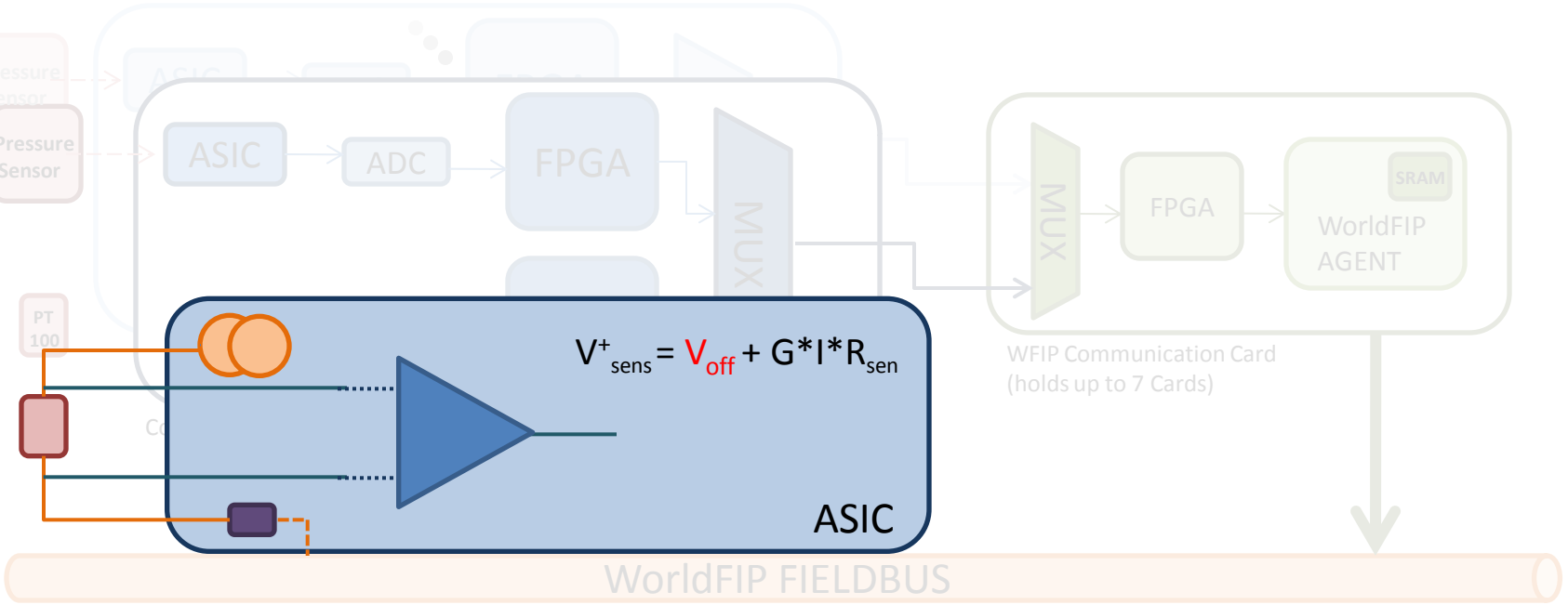


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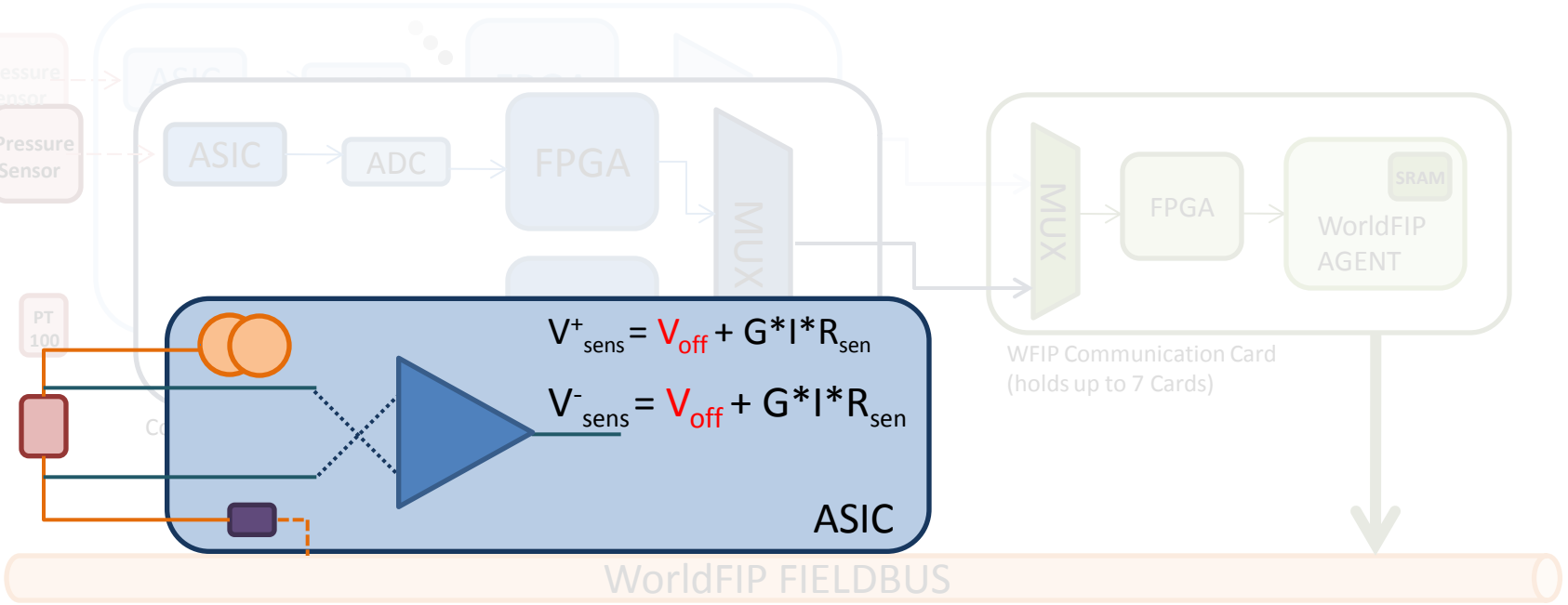


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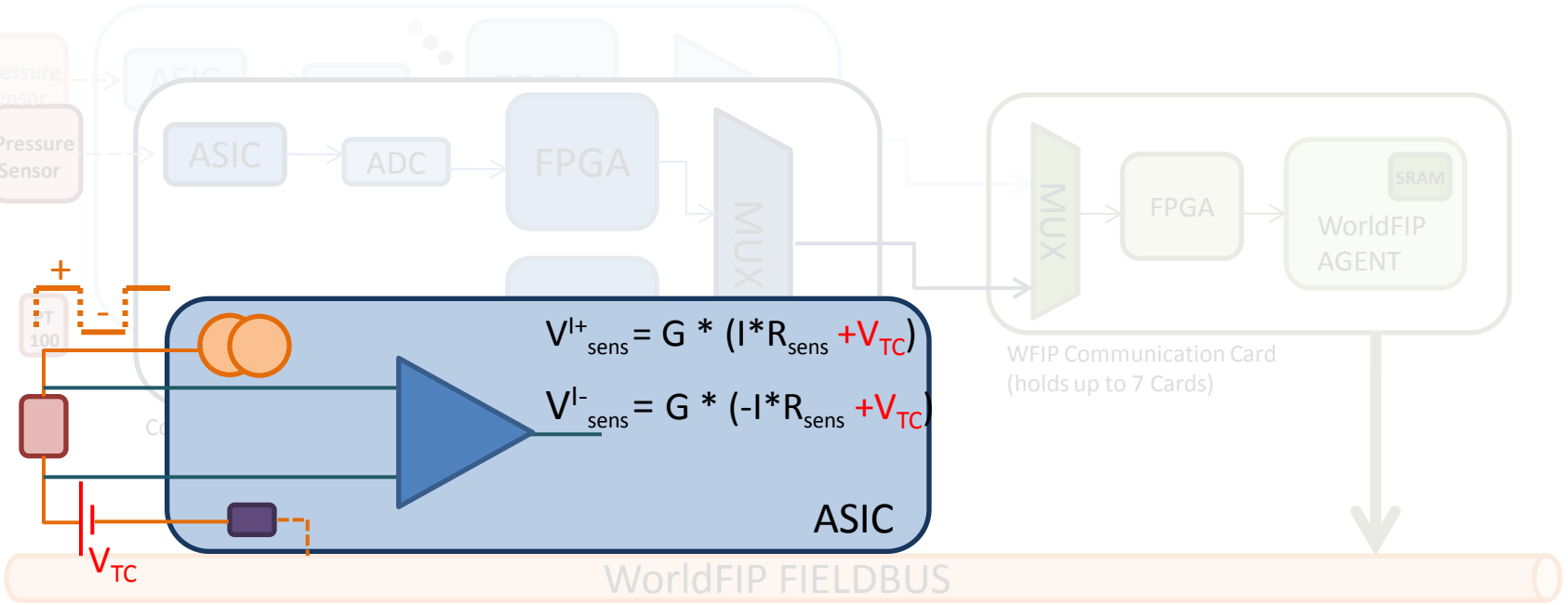


## High Accuracy main features

- Auto-calibrated System: high precision resistor measured every time a variable measurement is taken and correction of amplifier offset by amplifier input inversion as well as correction of cable [illegible] current inversion.

TC effects