



# Qualification Results on Power Converters *for HL-LHC Radiation Levels*



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## Presentation Purpose. *Why are we here?*

**Expose** the **results** obtained during radiation tolerant qualification test campaign

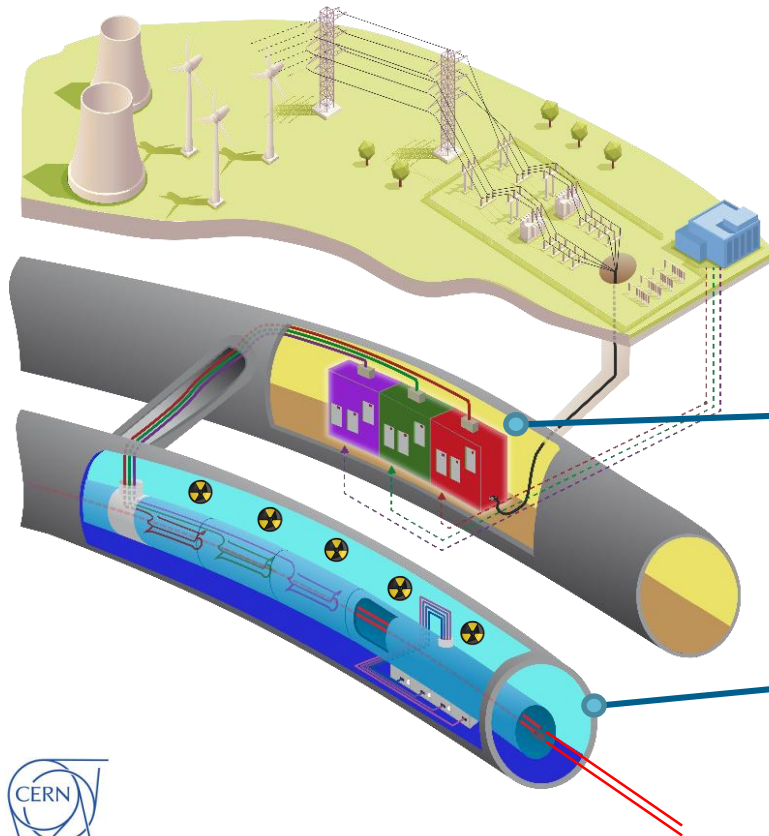
- For the Radiant-Tolerant Power Converters
  - R2E-LHC600A-10V
  - R2E-LHC4-6-8kA-10V
- Considering HL-LHC radiation levels and availability requirements

**Explain how** the test campaign is prepared and performed

- Indicate characteristics of the process that was followed
- Present it as a reference to be used in future similar test campaigns

# Introduction: Power converters & radiation

- HL-LHC makes use of more than 1700 power converters to power the electro-magnets that generate the magnetic field to guide the particles
- Most part of them are **critical** for the **operation** (1 fail = beam lost)
- The power **converter** operation can be **perturbed by** the leakage **radiation** generated by the beam.

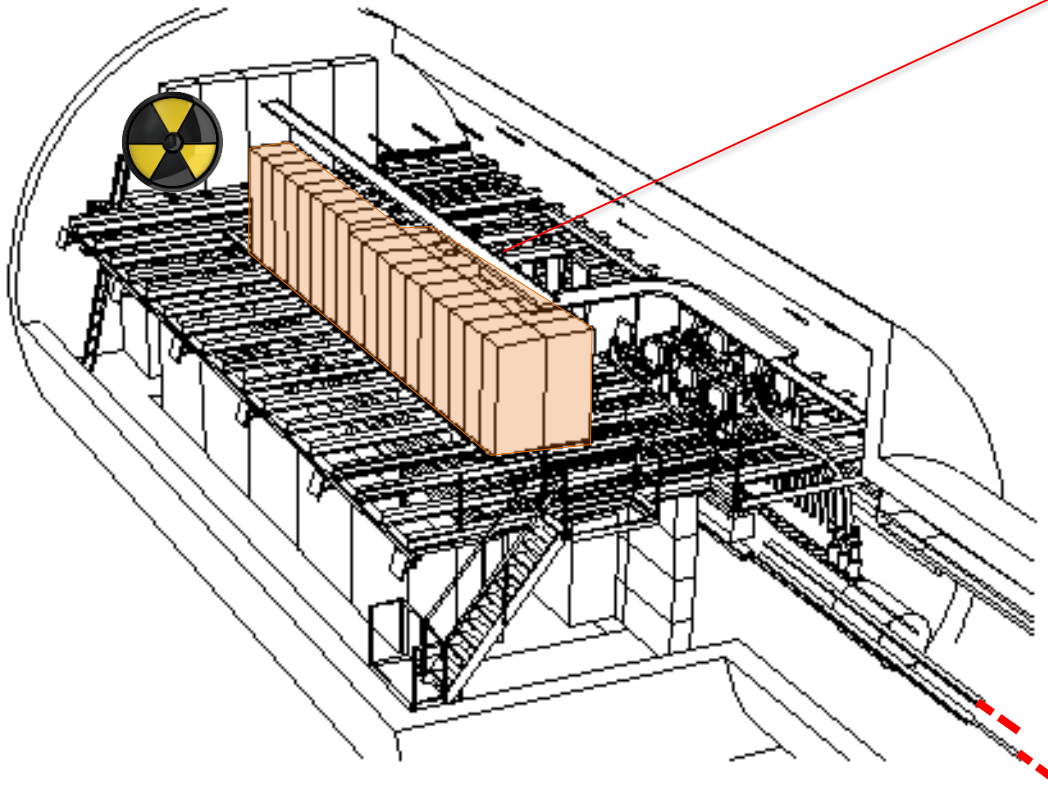


Normally the converters are installed in parallel galleries far away from the beam, radiation protected

Gallery to locate the electro-magnets and beam

# Why a Radiation-Tolerant Validation is Required?

- Installing converter in parallel galleries can be too costly
- 100 x R2E-LHC600A-10V & 60 x R2E-LHC4-6-8kA-08V power converters are located in **irradiated areas**
  - The **radiation** failures  $\Rightarrow$  **low availability**  $\Rightarrow$  **risks** the accelerator **operation**



Converters installed in “RR” galleries, too close to Beam

# What types of failures causes the radiation on converters

## Three Types of Radiation Damage in Power Converters

- **TID: Total Ionising Dose (cumulative)**
  - Causes a slow gradual degradation of device performance
  - Proportional to the dose
- **NIEL: Non-Ionising Energy Loss (cumulative)**
  - Causes a slow gradual degradation of device performance
  - Proportional to the 1 MeV equivalent neutron fluence
- **SEE: Single Event Effect (random)**
  - Causes an instantaneous degradation of device performance
  - Proportional to High Energy Hadron Fluence

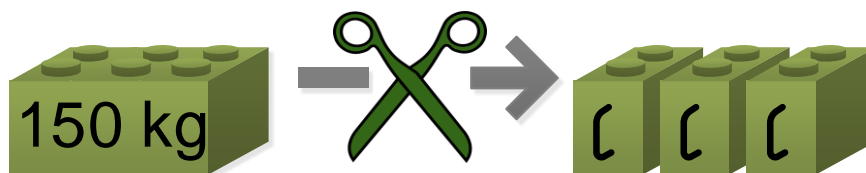
# R2E Power Converters. Modular Architecture

Modular & redundant design produced with COTs

R2E-LHC4-6-8kA-08V



R2E-LHC600A-10V



# Radiation-Tolerant Qualification Test Strategy

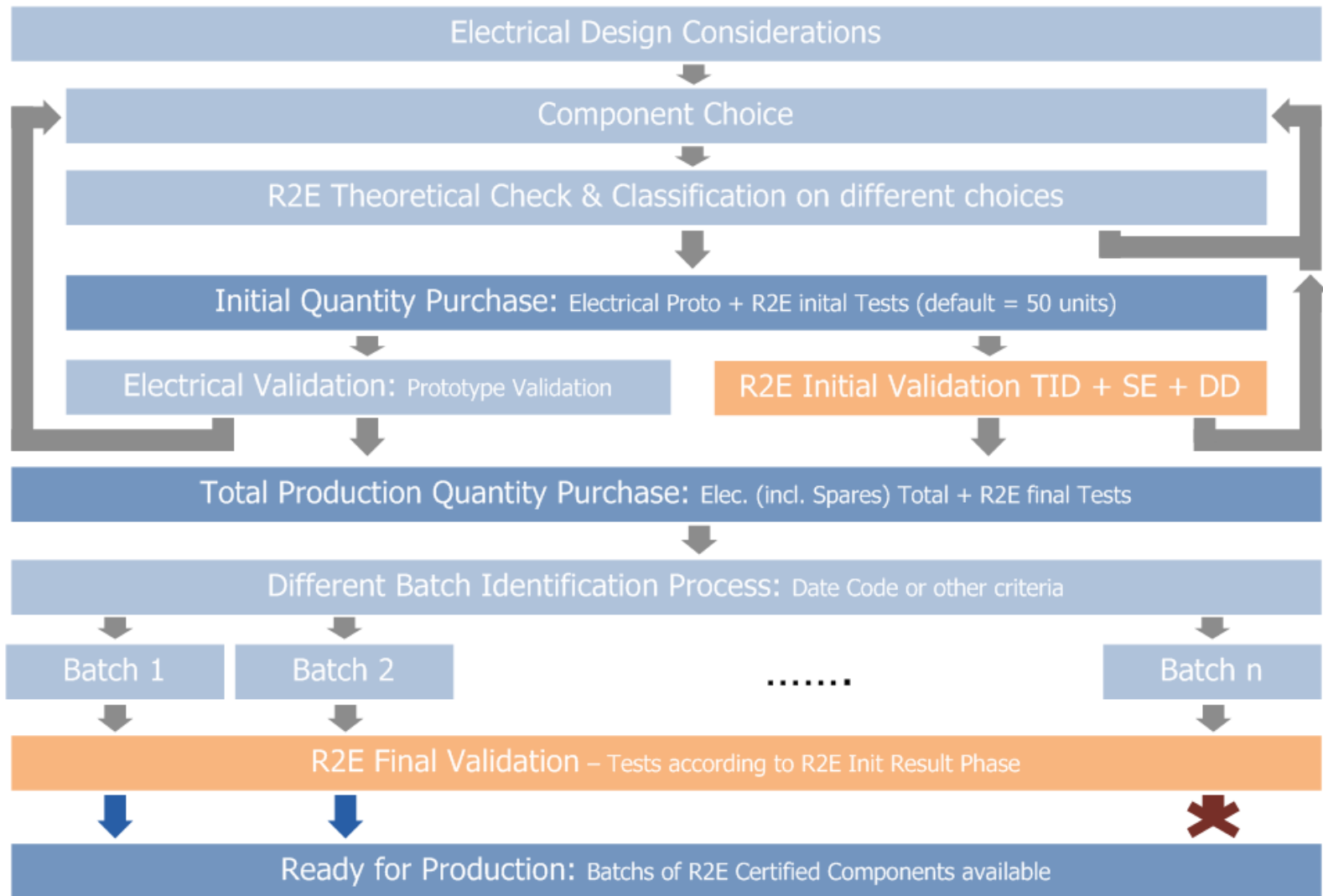
## Radiant-Tolerant COTs Validation

- **Validate COTs** before to be used in the series production
  - Test campaign performed one year ago
  - All component **batches** were **validated under radiation**

## Radiant-Tolerant Power Converter Validation

- **Validate** operative power **converters** meanwhile are irradiated
  - **Determine** the **radiation level objectives** required to validate the power converters. *Statistical analysis*
  - Design a **test bed** for the number of modules to test
  - **Execute** the **test** according to the plan
    - **Upgrade** the power converter **design** if result is not satisfactory
    - **Repeat** the test up to validate the power converter

# Radiation-Tolerant COTs Validation Process



# Radiation-Tolerant Power Converters Validation: Test Objectives

## Test Objectives:

- How many modules shall be irradiated
- Characteristics of the radiation to perform the test

## Statistical analysis performed to determine test objectives considering:

- HL-LHC maximum radiation levels and availability requirements

Locations	1-MeV neutron equ. fluence (cm <sup>-2</sup> )	HEHeq fluence (cm <sup>-2</sup> )	Dose (Gy/y)	Maximum Beam dumps tolerated per year
RR13 RR17 RR73 RR77 RR53	1 10 <sup>10</sup>	3 10 <sup>9</sup>	3	≤1 [R2E-LHC600A-10V] ≤2 [R2E-LHC4-6-8kA-10V]

*HL-LHC maximum radiation levels determined by FLUKA simulations*

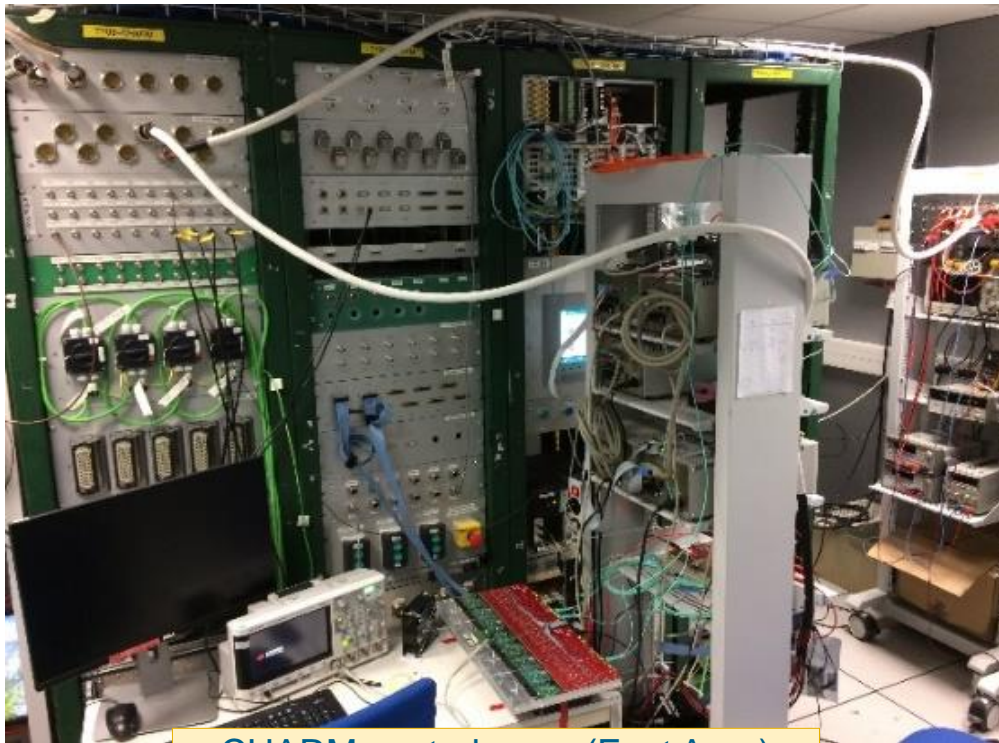
- Characteristics of testing irradiation facility
  - Characteristics of radiation available: Dose, 1 MeV neutron fluence, HEHeq fluence
  - Space to install the power converters
- Power Converters Architecture
  - Redundant modules provide more availability vs radiation failures

*More details in: EDMS#1741714*

# Where the power converters were irradiated?

## Radiation-Tolerant Converters were irradiated at CHARM

- Irradiation Facility able to test a big power converter
- Features a wide spectrum of radiation types and energies.
- Features in few weeks 20-yr under HL-LHC conditions



CHARM control room (East Area)



Converter under radiation

# CHARM Facility Layout

## Target configuration

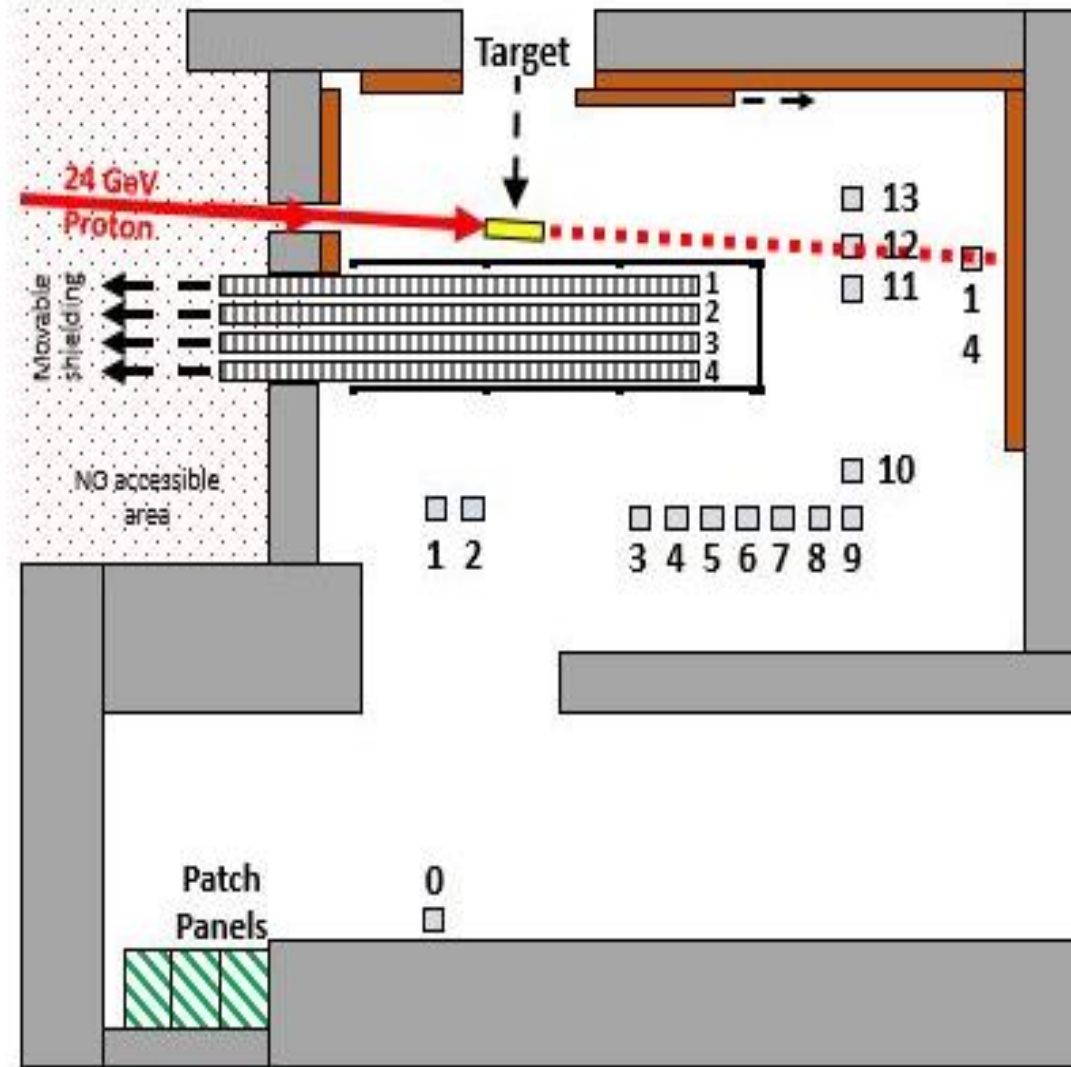
- NT  - Empty
- AIH  - Aluminium Hole
- Al  - Aluminium
- Cu  - Copper

## Type of shielding:

- 1 - Concrete
- 2 - Iron
- 3 - Iron
- 4 - Concrete

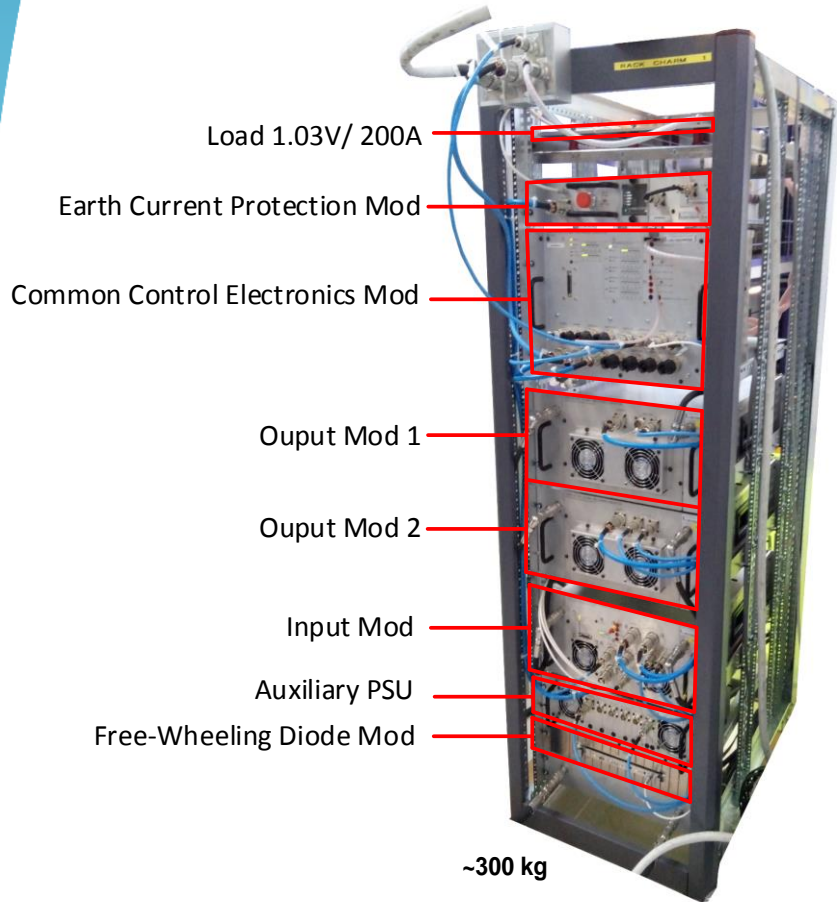
## Shielding Configuration:

-  Inside
-  Outside

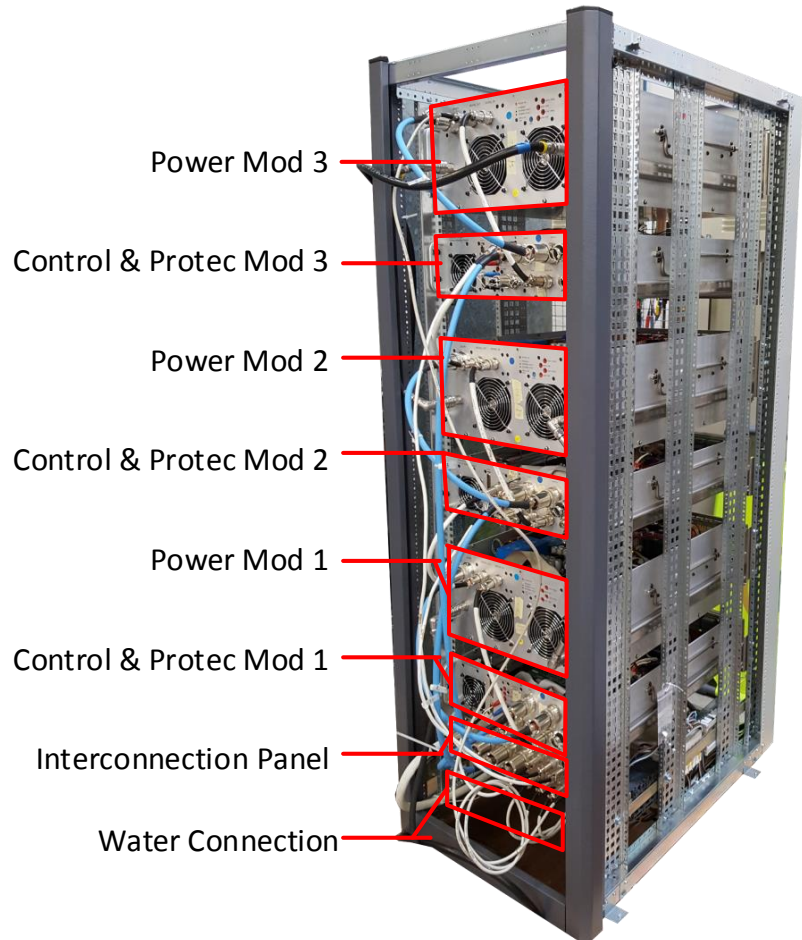


# Power Converters Testing Racks

*R2E-LHC4-6-8kA-08V Testing Rack*

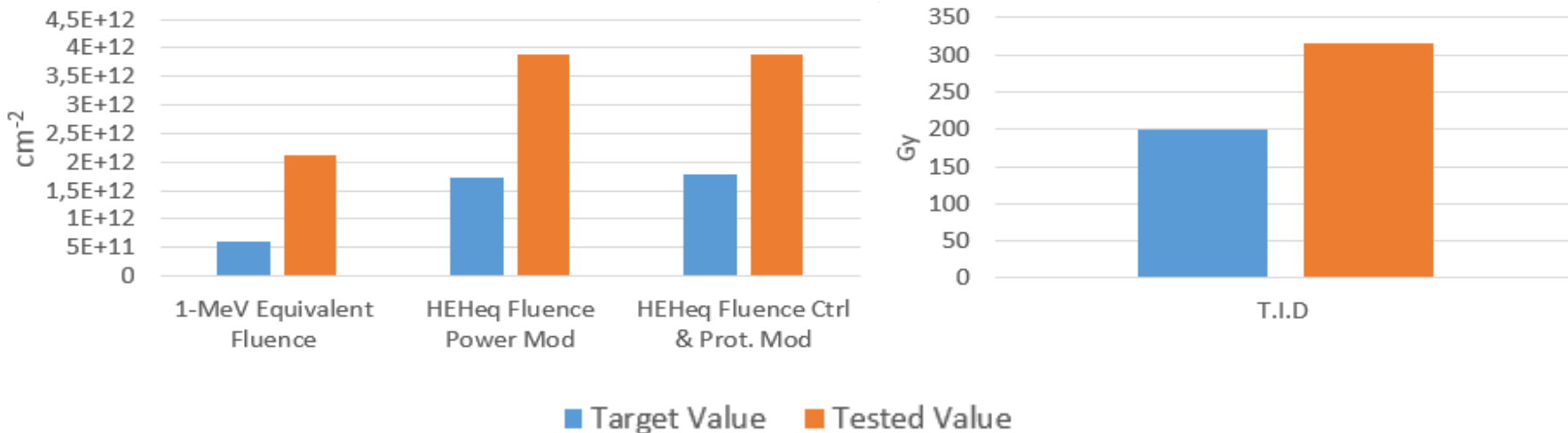


*R2E-LHC600A-10V Testing Rack*

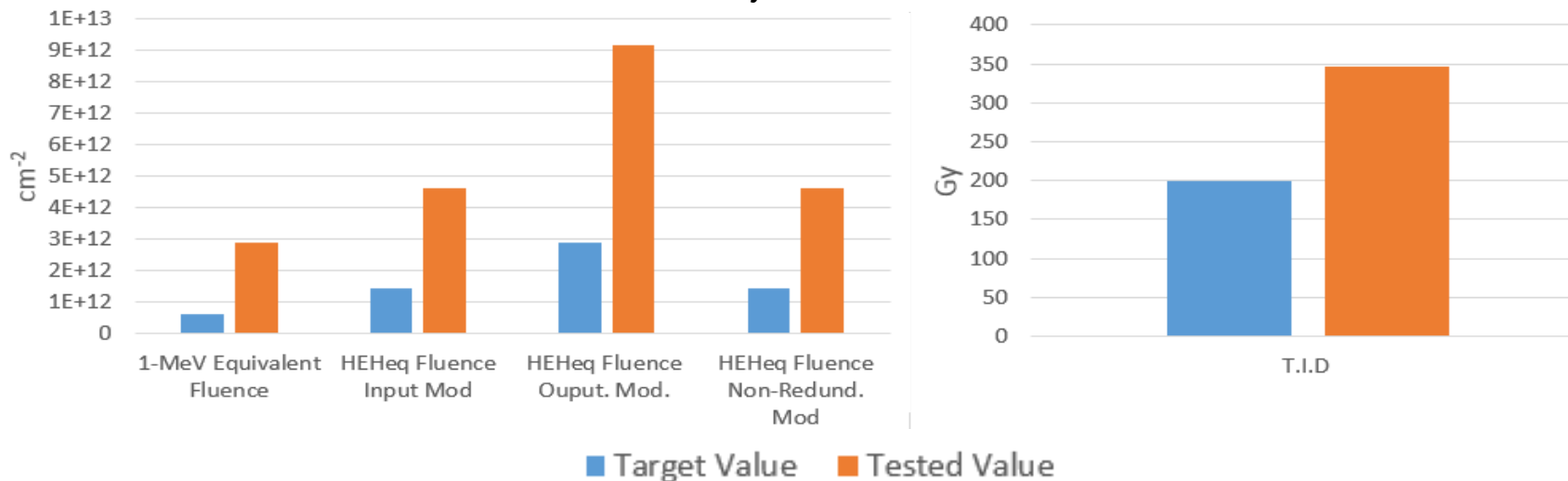


# Power Converters Radiation Tolerant Test Results

Radiation level results VS objectives for R2E-LHC600A-10V



Radiation level results VS objectives for R2E-LHC4-6-8kA-08V



**No SEE failures were observed at system level!**

# Conclusions and Achievements

- Project directs outputs
  - Converters validated for HL-LHC radiation and availability needs
  - Ready to start the series production for a targeted installation in LS2
  - Expected objectives exceeded
  - Detailed reports available in EDMS
    - R2E-LHC4-6-8kA-08V: [EDMS#1841689](#)
    - R2E-LHC600A-10V: [EDMS#1851356](#)
  
- TE-EPC wide output
  - Experience accumulated (design, test & management)
  - Useful for the next R2E converters (120A & 60A) to design

# Big Team Supporting Test Campaign

- FROM TE-EPC-LPC
  - Jonathan Braun TE-EPC-LPC *Design Engineer*
  - Damien K. Tiné TE-EPC-LPC *Design Engineer*
  - Raul B. Bianchi TE-EPC-LPC *Project Technician*
  - Maxime Sardano TE-EPC-LPC *Project Technician*
  - Benoit Favre TE-EPC-LPC *Project Technician*
  - L. Lionel Foro **TE-EPC-LPC** TE-EPC-LPC *Doctor Engineer*
- From CHARM Facility
  - Salvatore Danzeca *CHARM Coordinator*
  - Jérôme Lendaro *CHARM Technician*
  - Chiara Cangialosi *CHARM Dose Monitoring*
  - Pascal Brunero *CHARM Transport and Logistics*
  - Florent Philippon *CHARM Radioprotection*

**Thanks for you attention  
Questions?**

# BACKUP SLIDES

# Calculation of Radiation Level Test Objectives

6kA represents 90% of these type of converter in operation

$$A_{PS6kA} = A_{ILMT} \cdot A_{PSU} \cdot A_{PP} \cdot A_{EARTH} \cdot A_{FWD} \cdot A_{COCE}$$

$$A_{CP} = A_{COCE} = A_{FWD} = A_{EARTH}$$

$$A_{PSU} = A_{ILMT} = 1$$

$$[A_{PS6kA} = A_{PP} \cdot A_{CP}^3]$$

$$A_{PP} = (2 \cdot A_{SUB} - A_{SUB}^2)^{10}$$

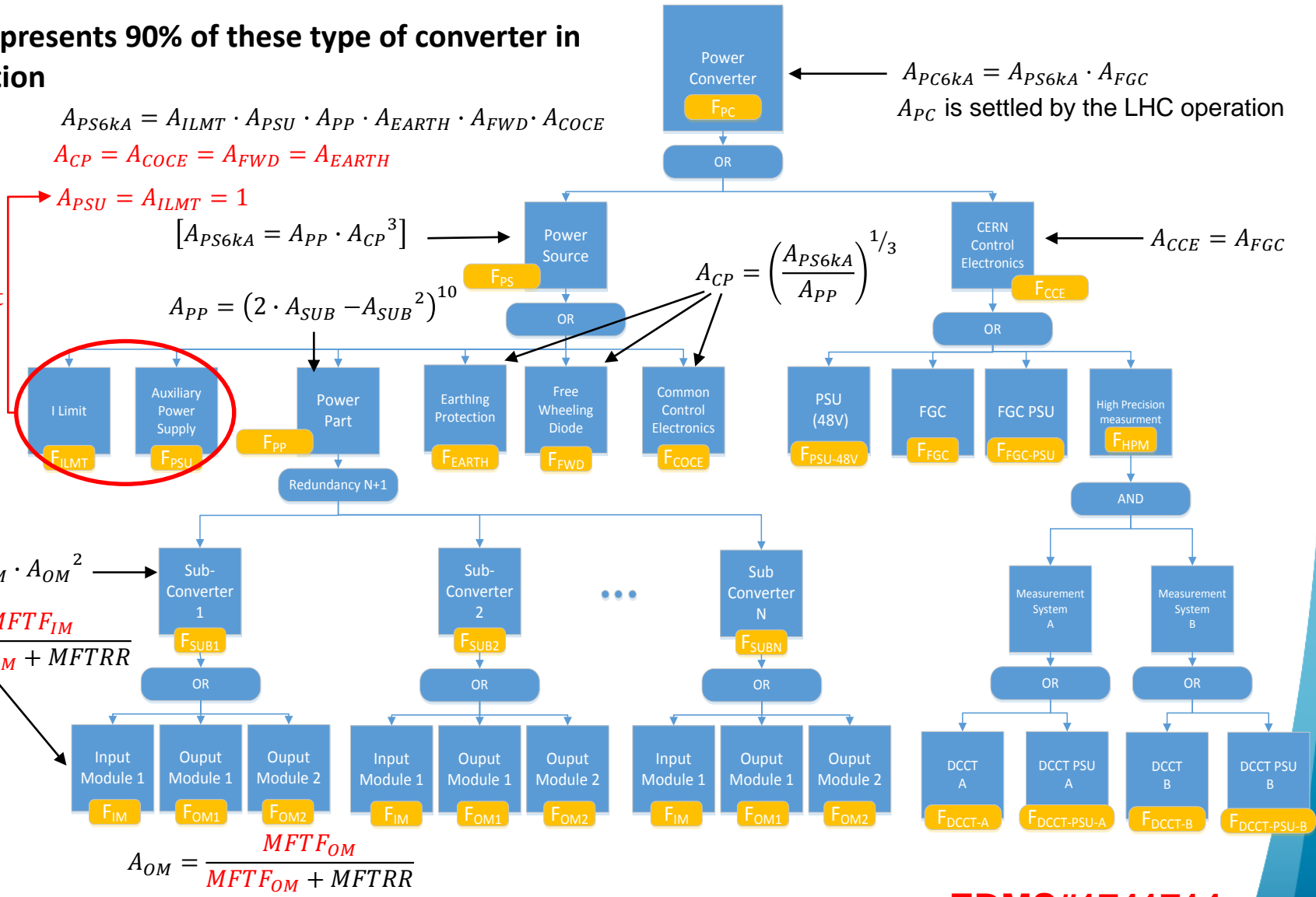
$$A_{CP} = \left( \frac{A_{PS6kA}}{A_{PP}} \right)^{1/3}$$

$$A_{PC6kA} = A_{PS6kA} \cdot A_{FGC}$$

$A_{PC}$  is settled by the LHC operation

$$A_{CCE} = A_{FGC}$$

Limit & PSU Rad – tolerant



$$A_{SUB} = A_{IM} \cdot A_{OM}^2$$

$$A_{IM} = \frac{MFTF_{IM}}{MFTF_{IM} + MFTRR}$$

$$A_{OM} = \frac{MFTF_{OM}}{MFTF_{OM} + MFTRR}$$

**EDMS#1741714**



# Calculation of Radiation Level Objectives

Objectives	Power Module	Control & Protection Module
TID (Gy) <small>Per module</small>	200	200
1-MeV neutron fluence (cm <sup>-2</sup> ) <small>Per module</small>	6·10 <sup>11</sup>	6·10 <sup>11</sup>
HEHeq fluence (cm <sup>-2</sup> ) <small>Sum of modules</small>	1.73 10 <sup>12</sup>	1.79 10 <sup>12</sup>
Modules to test	3	3

*Radiation level objectives for R2E-LHC600A-10V*

Objectives	Output Module	Input Module	Each Non-redundant Module
TID (Gy) <small>Per module</small>	200	200	200
1-MeV neutron fluence (cm <sup>-2</sup> ) <small>Per module</small>	6·10 <sup>11</sup>	6·10 <sup>11</sup>	6·10 <sup>11</sup>
HEHeq fluence (cm <sup>-2</sup> ) <small>Sum of modules</small>	2.90 10 <sup>12</sup>	1.45 10 <sup>12</sup>	1.45 10 <sup>12</sup>
Modules to test	8	4	4

*Radiation level objectives for R2E-LHC4-6-8kA-08V*

# Power Converters Radiation Tolerant Test Results

Objectives	Target Value	Test Value
TID (Gy) Per module	200	<b>315</b>
1-MeV Equivalent Fluence (cm <sup>-2</sup> ) Per module	6·10 <sup>11</sup>	<b>2.11·10<sup>12</sup></b>
HEHeq Fluence Power Mod. (cm <sup>-2</sup> ) Sum of modules	1.73·10 <sup>12</sup>	<b>3.89·10<sup>12</sup></b>
HEHeq Fluence Ctrl & Prot. Mod. (cm <sup>-2</sup> ) Sum of modules	1.79·10 <sup>12</sup>	<b>3.89·10<sup>12</sup></b>

*Radiation level results VS objectives for R2E-LHC600A-10V*

Objectives	Target Value	Test Value
TID (Gy) Per module	200	<b>347</b>
1-MeV Equivalent Fluence (cm <sup>-2</sup> ) Per module	6·10 <sup>11</sup>	<b>2.9·10<sup>12</sup></b>
HEHeq Fluence Input Mod. (cm <sup>-2</sup> ) Sum of modules	1.45·10 <sup>12</sup>	<b>4.64·10<sup>12</sup></b>
HEHeq Fluence Output Mod. (cm <sup>-2</sup> ) Sum of modules	2.90·10 <sup>12</sup>	<b>9.2·10<sup>12</sup></b>
HEHeq Fluence Non-Redund. Mod. (cm <sup>-2</sup> ) Sum of modules	1.45·10 <sup>12</sup>	<b>4.64·10<sup>12</sup></b>

*Radiation level results VS objectives for R2E-LHC4-6-8kA-08V*

**No SEE failures were observed at system level!**

Detailed information in: [EDMS#1841689](#) for R2E-LHC4-6-8kA-10V  
[EDMS#1851356](#) for R2E-LHC600A-10V

# Test Campaign Plan

## Stages to validate the power converters

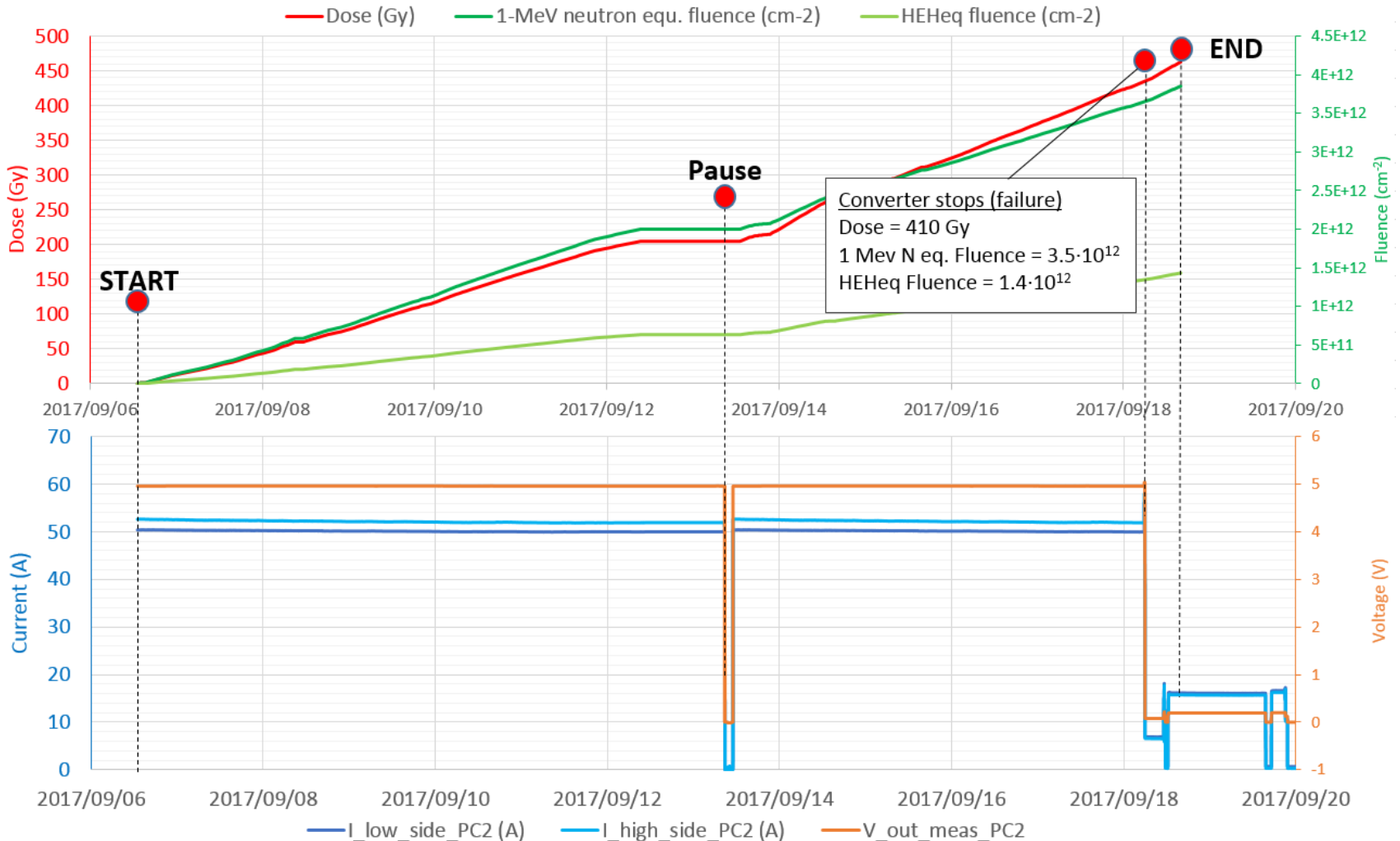
- Stage 1: Dry run
  - The converter is tested during one week in an area non-irradiated
- Stage 2: Irradiated run
  - The calculated number of converters are irradiated during time calculated
- Stage 3: Buffer area
  - The converter stay in a buffer area cooling down

Note: Dump power converter used to detect the initial design errors

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Dry	4-6-8 kA			4-6-8 kA			600A	600A		4-6-8 kA		600A x2			
RAD		4-6-8 kA	4-6-8 kA		4-6-8 kA	4-6-8 kA		600A	600A	600A	4-6-8 kA	4-6-8 kA	600A x2	600A x2	
Buff				4-6-8 kA			4-6-8 kA		600A		600A		4-6-8 kA		600A x2

*R2E Power Converters qualification campaigns timeline. Dump converters in red colour.*

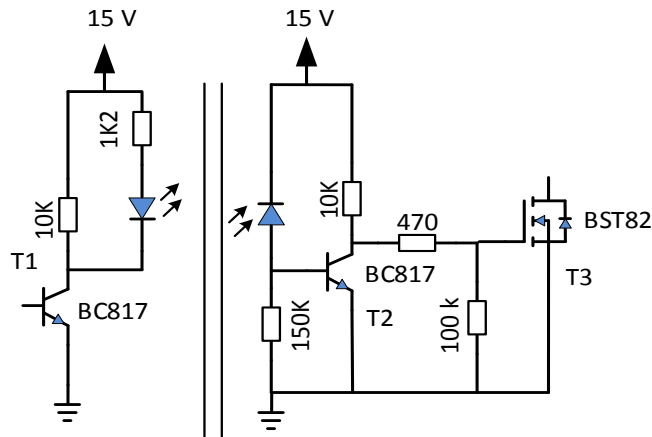
# Qualification Test Results: *Example*



R2E-LHC600A-10V R2E Test results in Session 3

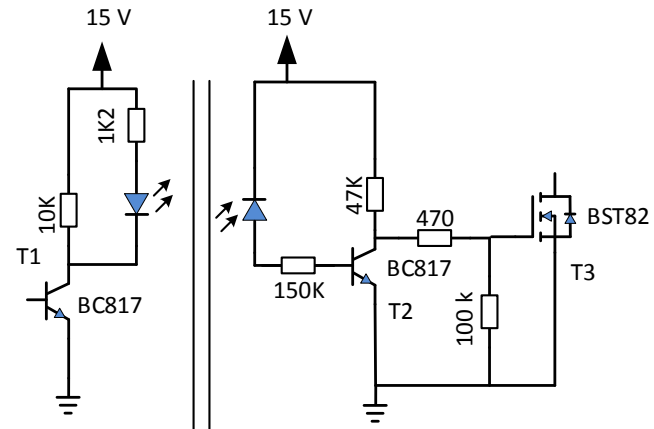
## OPTICAL ISOLATION CIRCUIT

### ORIGINAL CIRCUIT



**Optocoupler gain not enough to saturate T2**

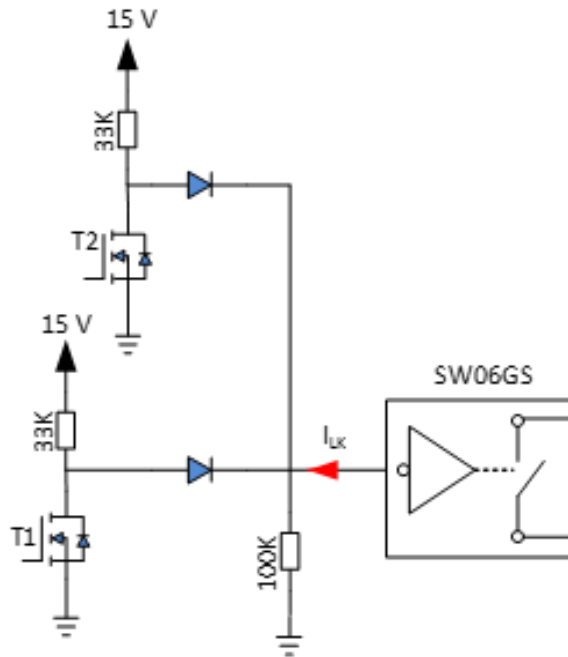
### UPGRADED CIRCUIT



**Current required to saturate T2 transistor reduced**

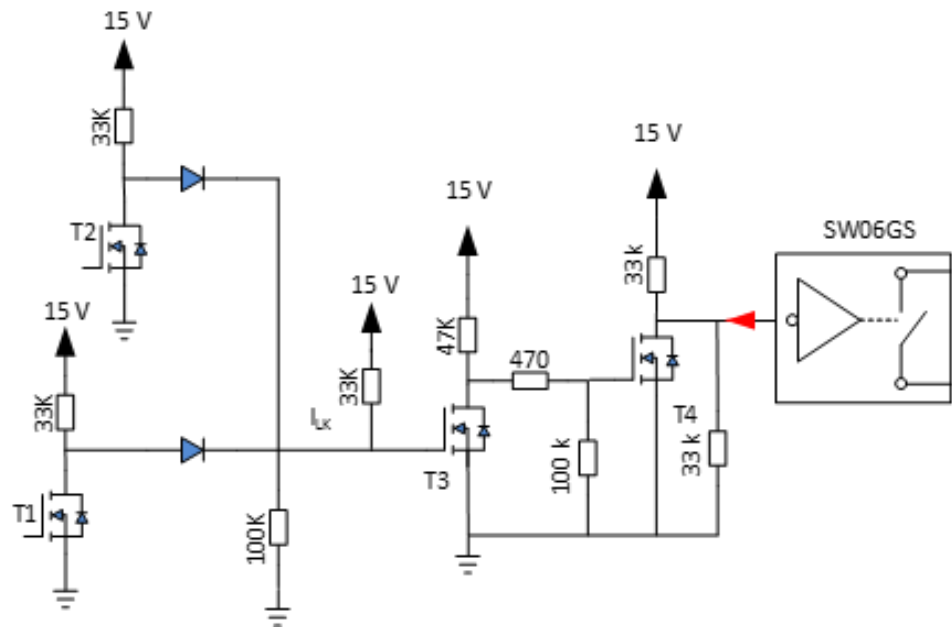
## ANALOG SWITCH CIRCUIT

### ORIGINAL CIRCUIT



Leakage current too high to let the pull down resistor to switch off the analog switch device

### UPGRADED CIRCUIT



Pull down resistor is substituted by a mosfet transistor to sink the leakage current

# Why is it necessary the test campaign at CHARM

In 2010 CERN decides to change:

- 104 x **LHC600A-10V** power converters located in **irradiated areas**
- 60 x **LHC4-6-8kA-08V** power converters located in **irradiated areas**
  - The **Industrial** design was **not** conceived to operate under **radiation**
  - The **low availability** puts in risk the accelerator operation

**HL-LHC radiation levels are higher than in LHC:**

Locations	1-MeV neutron equ. fluence (cm <sup>-2</sup> )	HEHeq fluence (cm <sup>-2</sup> )	Dose (Gy/y)	Maximum Beam dumps tolerated per year
RR13 RR17 RR73 RR77 RR53	1 10 <sup>10</sup>	3 10 <sup>9</sup>	3	≤1 [R2E-LHC600A-10V] ≤2 [R2E-LHC4-6-8kA-10V]

*HL-LHC maximum radiation levels determined by FLUKA simulations*

New **R2E Converters** shall be designed and **validated**

- **CHARM** features in few weeks **20-yr**s under **HL-LHC** conditions



# Power Converters Testing Racks

*R2E-LHC4-6-8kA-08V Testing Rack*



*R2E-LHC600A-10V Testing Rack*

