CERN

# Designing radiation tolerant converter up to 500 Gy for HL-LHC

**Yves Thurel**

*With inputs from B. Favre, J. Clar, B. Jacque Sermet, J. Milovanovitch*

CERN, *for* 11th HL-LHC Collaboration Meeting, 2021-10 @ CERN

*Document source* *https://edms.cern.ch/document/2646584/*

*Meeting link (indico)* *https://indico.cern.ch/event/1079026/*

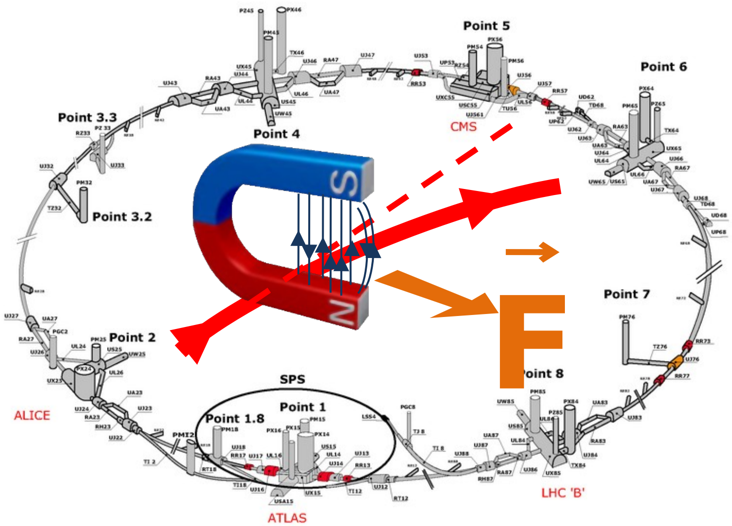
# Introduction

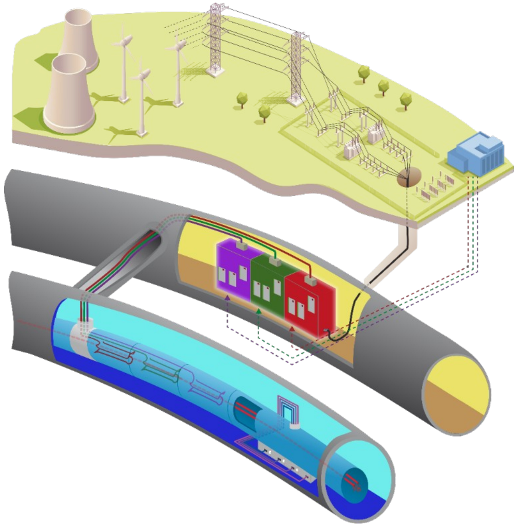
## This talk intends to

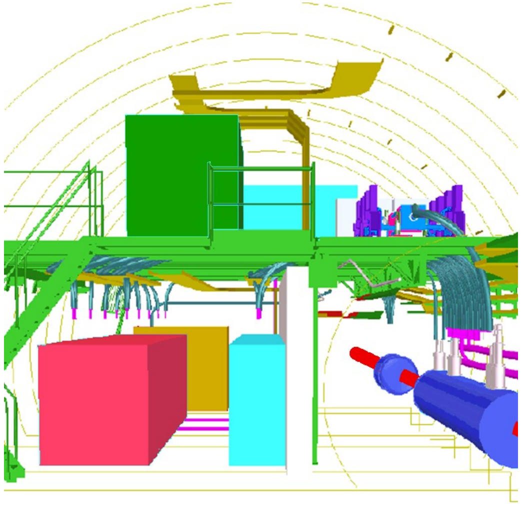
- Describe the converters of interest, enhancing their operating conditions
- Give some hints of our learnt lessons from previous rad-tolerant design
- **Put the emphasis on the design paths of a power converter up to** 500 Gy.

# LHC converters







*Power Converters*

*Beam*

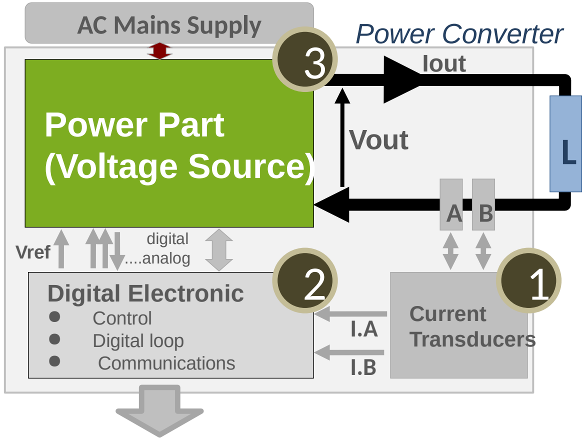
*1700 units, installed underground over 27 km, guiding beam…*

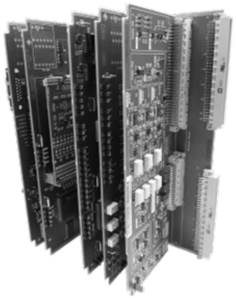
*… located in adjacent alcoves, not exposed to radiations for some…*

*… but others still close enough from beam to suffer from radiations.*

# LHC converters

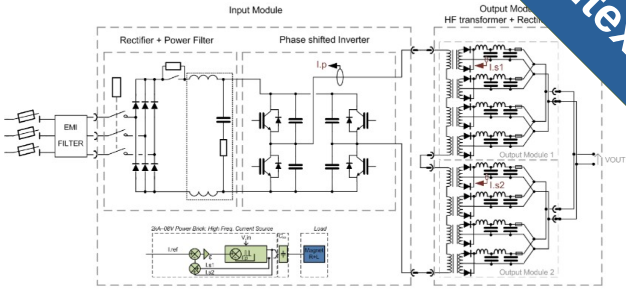

Few families, with output current in [60; 13 000] A

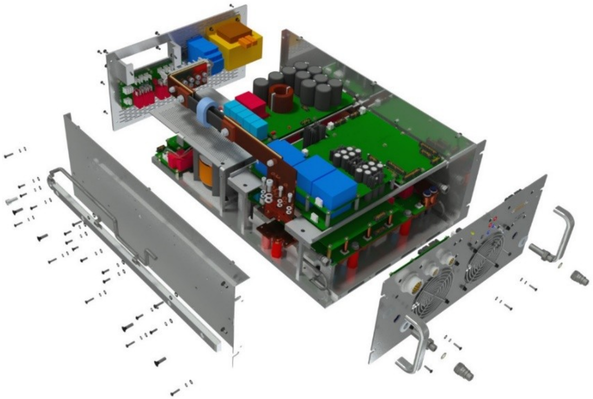


*Control (digital):*
*S. Uznanski*
*NSREC2017*

This talk focus on the *power part…*



*… using only analogue components.*

# 60A & 120A converters upgrade

# Context – Radiation Levels in LHC

Environment

## Radiation levels (HL)

- 600A / kA already renewed
- 60A / 120A highly exposed

| Area | Dose [Gy/year] | 1MeV n-eq. [nb/($cm^2$.year)] | E>20MeV H… [/($cm^2$.year)] |
|---|---|---|---|
| **Tunnel**<br>**R2E-HL-LHC60A-10V 72 units**<br>(072 ( cell[12;16] Pt1,2,5) | 08x 12L/R2: <10<br>08x 12L(1/5): <10<br>08x 12R(1/5): <03<br>48x 14/16-L/R-1/2/5: 1.5 | <1E11<br>3E10 | **<1E10**<br>**3E9** |
| **Tunnel**<br>**LHC60A-08V (678 - 72) units**<br>**R2E-HL-LHC60A-10V 72 units**<br>(550x Cell>17)<br>(120x cell[12;17] Pt3,4,6,7,8) | **0.5** | 3E10 | **3E9** |
| **RR13/17**<br>**R2E-HL-LHC120A-10V 36 units**<br>**R2E-LHC600A-10V 28 units**<br>**R2E-LHC6kA-08V 26 units**<br>**R2E-LHC6kA-08V 04 units**<br>** installed with 5kA DCCT* | level-0: **15**<br>level-1: **25** | level-0: **7E10**<br>level-1: **7E10** | level-0: **1.0E10**<br>level-1: **1.4E10** |
| **RR53/57**<br>**R2E-HL-LHC120A-10V 36 units**<br>**R2E-LHC600A-10V 28 units**<br>**R2E-LHC6kA-08V 26 units**<br>**R2E-LHC6kA-08V 04 units**<br>** installed with 5kA DCCT* | level-0: **15**<br>level-1: **25** | level-0: **7E10**<br>level-1: **7E10** | level-0: **1.0E10**<br>level-1: **1.4E10** |
| **RR73/77**<br>**R2E-LHC600A-10V 48 units**<br>**R2E-HL-LHC120A-10V 20 units**<br>**R2E-HL-LHC600A-10V 02 units** | **0.5** | 4E9 | **2E8** |
| **UL14/16**<br>**R2E-HL-LHC120A-10V 16 units**<br>**R2E-LHC600A-10V 02 units** | **0.01** close to US15/17<br>**0.10** in UL14/$16_{middle}$<br>**1.00** close to UJ14/16 | **2E8** close to US15/17<br>**1E9** in UL14/$16_{middle}$<br>**1E10** close to UJ14/16 | **2E7** close to US15/17<br>**1E8** in UL14/$16_{middle}$<br>**1E9** close to UJ14/16 |
| **UA/J(s), TZ76, UJ33, UR15/57**<br>**Some local exception in Point 6**<br>**"sea level" expected (Th. n. excepted)** | **0.01** | [5E6; 2.5E7] | **[1; 5]E6** |

# Previous converters currently installed in LHC

## LHC60A-08V current status | LHC

- 750 converters installed under dipoles
- Original design (2000)
- COTS being used not fully traced
- End Of life Dose [25;50] Gy
- Considered as “*immune*” to SE


## R2E-HL-LHC60A-10V challenge | HL-LHC

- 072 units under high level of radiation
- HL-LHC Level increase
  - Dose: 1 Gy / year ► 10 Gy / year
  - HEH $_{E>20\ MeV}$: 5E8 ► 1E10 / cm$^2$ / year
  - ***A new design is required.***

72 units in pt1-5-2 cells 12/14/16

# Previous converters currently installed in LHC

## LHC120A-10V current status | LHC

- 300 converters in total
- Unknown sensitivity to dose (not tested)
- Standard design (non rad-tol / 2003)

## R2E-HL-LHC120A-10V challenge | HL-LHC

- 92 units under radiation stress in RR1/5/7
- HL-LHC Level increase
  - Dose: 1 Gy / year ► 25 Gy / year
  - HEH $_{E>20\ MeV}$: 5E8 ► 1.4E10 / cm$^2$ / year
  - ***A new design is required.***

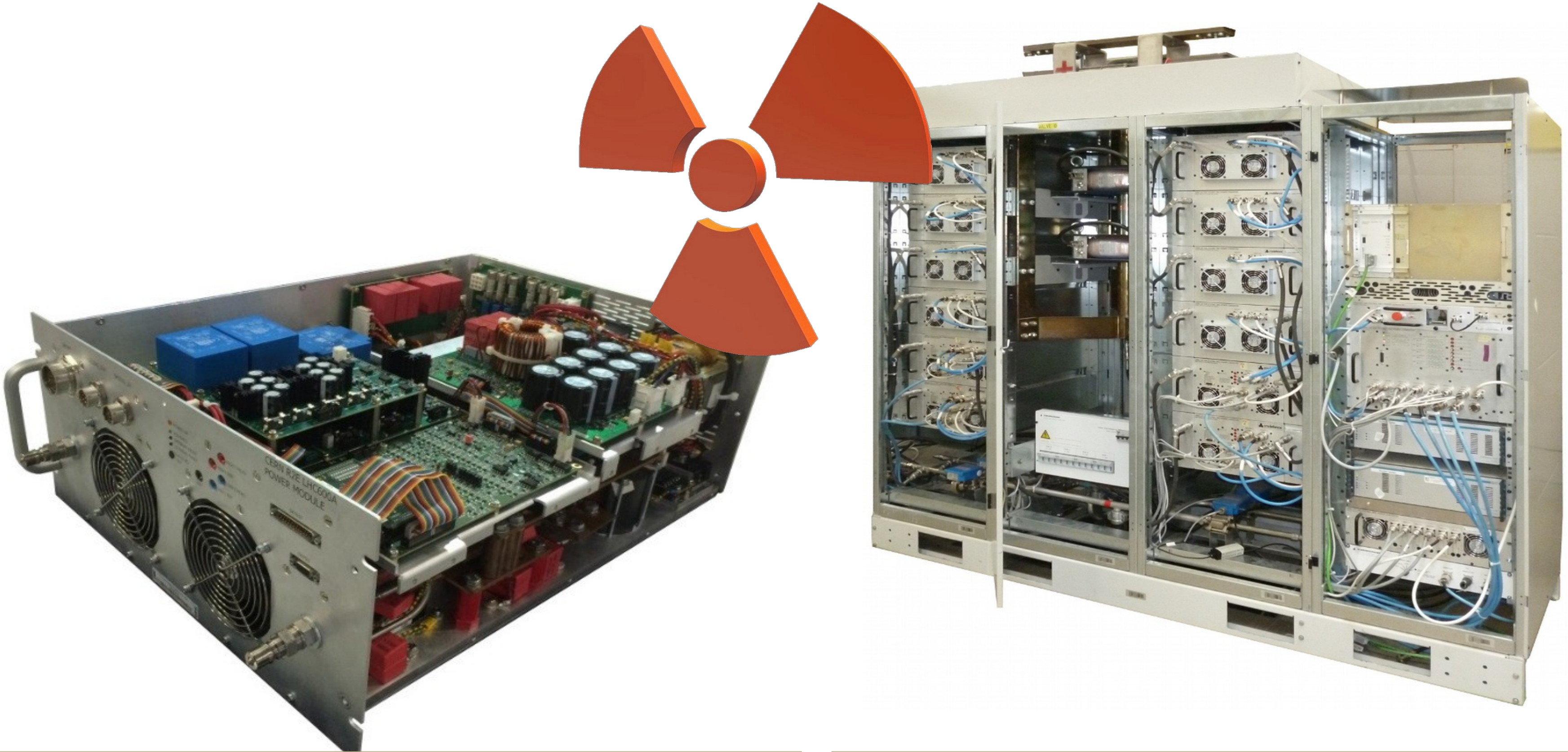
92 units in LHC-RR1-5-7

# Lessons learnt from previous designs / projects

## With new challenges put in perspective

# Lessons based on R2E-Converters installed in LHC @ LS2

Lessons learnt



100x R2E-LHC600A-10V installed in LS2

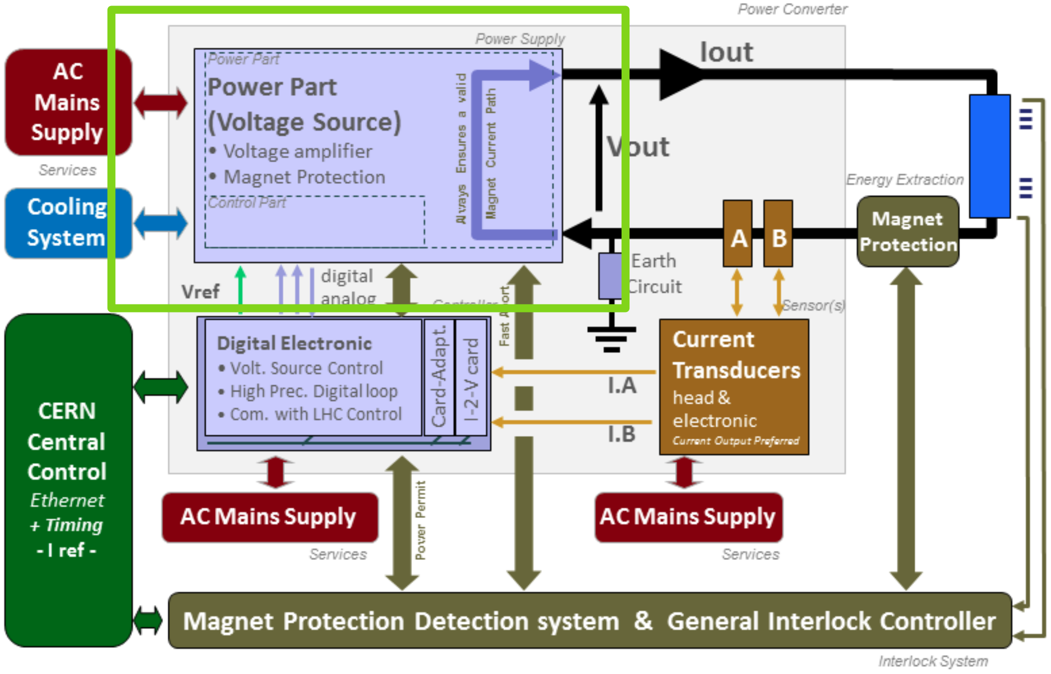
60x R2E-LHC4-6-8kA-08V installed in LS2

# Lessons learnt from recent R2E project

Lessons learnt

## Findings

- A power source can be designed with standard elementary components, not requiring high complexity integrated devices (devoted to FGC in R2E-EPC).




A high performance converter can be designed using very standard semiconductors:

- Thyristors, Bipolar & Mosfet Transistors, IGBTs.
- Op-Amps, comparators.
- Diodes, voltage references,
- PWM (one of the most complex component!)

# Lessons learnt from recent R2E project - Radiation

Lessons learnt

## Radiation Event Mitigation / Risks

- Single events can be very well managed with gold simple rules
- Dose degradation (TID, DD) must be considered very seriously above 50 Gy
- Component Testing effort vs radiation should be focusing on critical components
- Whole converter testing effort versus radiation is essential (CHARM)
  - It is a key point of the project & address some failures mechanism **difficult to control / predict**
  - Gives an opportunity **to test many components in one go**, in their specific use conditions!
  - Reinforces **the trust in design**, before installation.
  - **Should not be ideally placed too late, to be able to react!**

# Lessons learnt from recent R2E project - Radiation

Lessons learnt

## Management of COTS component purchasing process highlight

- All semi-conductors purchased by CERN to be sent to external producing companies… was a tough task, certainly not justified for most of them.
- Sensitive COTS must be carefully treated, others addressed in lighter way.

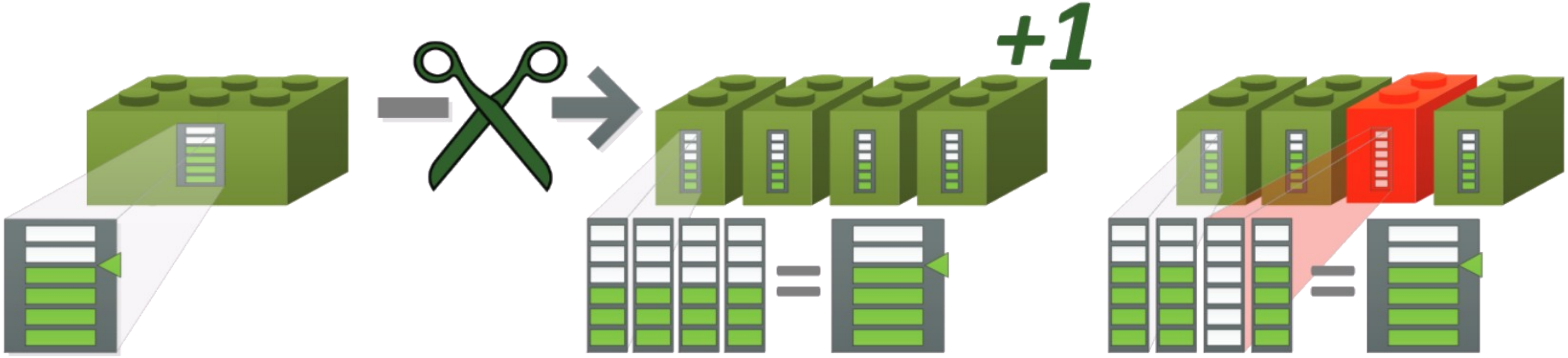
## New converter are redundant...

**… as much as possible**

# Context – (60;120)A Joined Optimized Design

## Converter redundancy applied to R2E-HL-LHC60A & R2E-HL-LHC120A

- Generalization of redundancy concept to new (<120A) R2E versions.
  - New R2E-LHC600A & kA converters are now all redundant.
- Optimization of design effort
  - **One 60A Power Source only to design two converters**
- **Cope with HL-LHC availability target (radiation or not induced failures)**

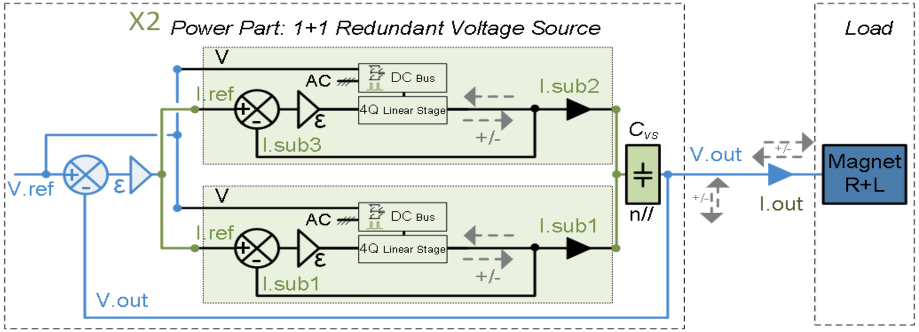


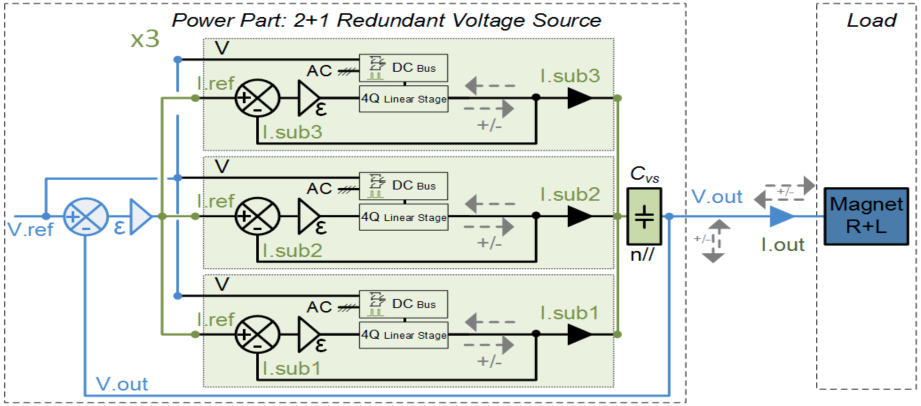
# Redundancy Impact on converter reliability

Redundancy

## Converter redundancy highlights

- 060A converters = 2 x 60A in // (n+1 = 1+1) = 2.0 x installed power
- **120A converters = 3 x 60A in //** (n+1 = 2+1) = 1.5 x installed power
- Redundancy is performed through power current sources (sharing current load)



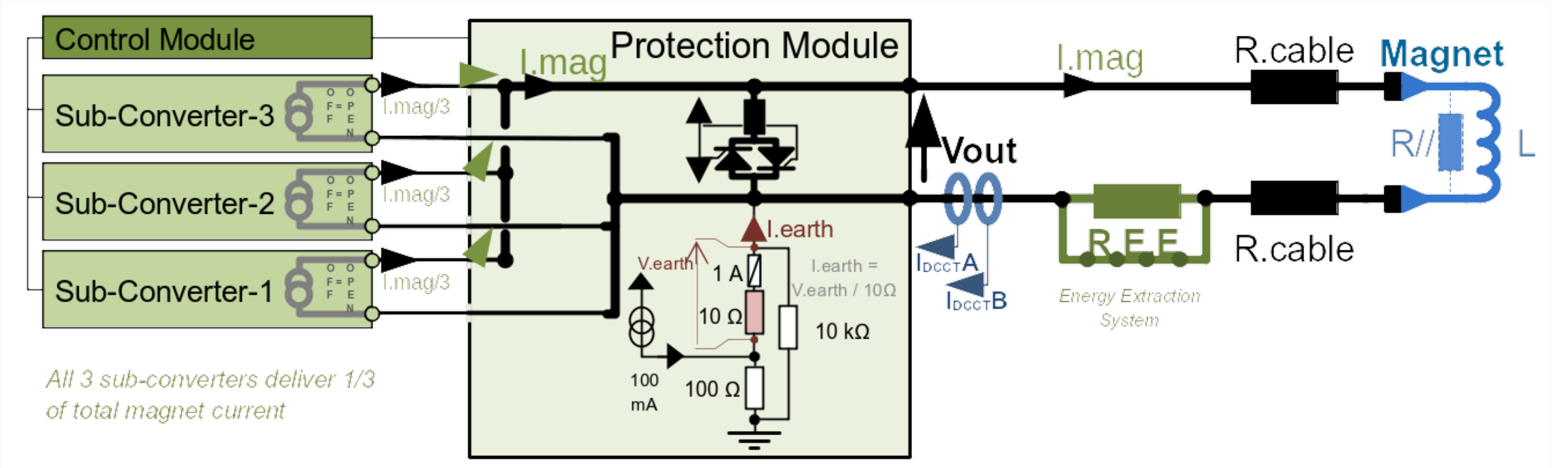




| R2E-HL-LHC60A-10V | R2E-HL-LHC120A-10V |
| --- | --- |

# Redundancy Impact on converter reliability

Redundancy

## Converter redundancy




| Case of R2E-HL-LHC120A-10V | |
|---|---|
| 3 Power Modules deliver output power in 2+1 redundant config. | Redundant |
| 1 Control Module in charge of the Power Source Control | Not-Redundant |
| 1 Protection Module in charge of the Magnet Discharge Path | Not-Redundant |

# Redundancy Impact on converter reliability

Redundancy

## Impact of redundancy choice on reliability

- Basis
  - 92 converters | 200 days of operation a year
  - Mean Time To Repair: 1 week (dependant on access)
  - Required MTBF are calculated for 1 LHC dump per year per line below (linked to module type).
    - Power Module operates always in n+1 redundant mode (two failures = 1 beam loss)
    - Control & Protection Module are “immediately “ critical module for availability.

| Case of R2E-HL-LHC120A-10V | Required MTBF |
|---|---|
| Power Module | 14 000 hours |
| Control Module | 450 000 hours |
| Protection Module | 450 000 hours |

# Redundancy Impact on converter reliability

Redundancy

## Impact of redundancy choice on reliability (MTBF ~ Single Event)

- Basis
  - 92 converters | 1E10 HEH E>20 MeV a year
  - Mean Time To Repair: 1 week (dependant on access)
  - Cross section are deduced from MTBF changing simply the units.

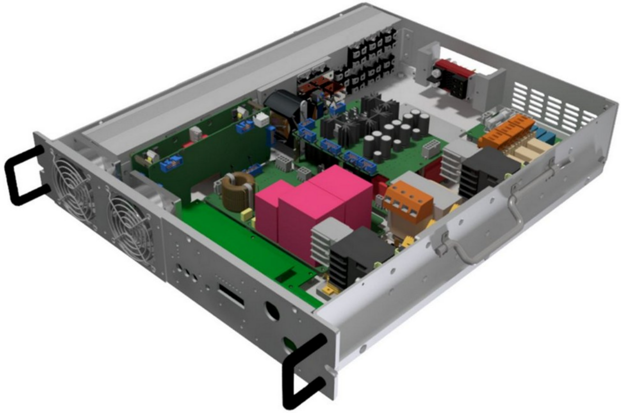
| Case of R2E-HL-LHC120A-10V | Required X-section |
| --- | --- |
| Power Module | 3.5 E-11 $cm^2$ |
| Control Module | 1.1 E-12 $cm^2$ |
| Protection Module | 1.1 E-12 $cm^2$ |

# Highlight on redundant design impact

Redundancy

## Impact on modules reliability – Output regarding SE sensitivity

- Redundancy helps a lot ! It reduces the power module required reliability of a factor 70 (x30 for 2+1 in case of 120A converter) vs critical non-redundant unit!
- Cross section of 3.5E-11 for a complete system, made of hundreds of COTS components is a real challenge
- Indeed, qualifying components at a sufficient level is almost impossible!
  - In most cases*, minimum determined minimum X-section will not be small enough to theoretically cover the design.



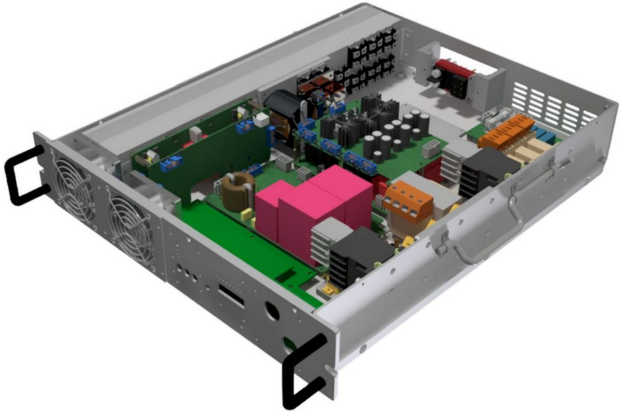
** A component surviving one day @ Charm (1E11 HEH) proves a X-section better*
*… but a converter comes with several hundreds of components more, all critical...requiring individual very low cpt x-section*

# Highlight on redundant design impact

Redundancy

## Impact on modules reliability – Output regarding SE sensitivity

- **Cross section of 3.5E-11 for a complete system, made of hundreds of COTS components** relies on using "non sensitive" components.
- A SOA for each component must be determined, and verified through 0-failure test, *as "far" as* possible:
  - Or multiply the number of devices under tests
  - Or use the highest possible fluency.



## General Approach

# Apply to SE, DD, DOSE radiation effects

# General approach SE & Dose: gold rules exist, use them!

## Applying gold known rules

- Minimize the number of references (test costs!) & classify them (class)
- Prefer the robust topologies (limiting stress on components like ZVS)
- Use the component in its known Radiation Safe Operating Area
- The easiest and the most solid gold rules when using COTS
  - Use only component found in “**list of qualified components**”
- The worst gold rule, when using COTS
  - Always be suspicious about all past conclusions / tests / qualified list.
  - Be aware a test on one component bobbin doesn’t give you the status of all others...

# Gold rule: don't fail component selection phase!

## A fine selection of all required components is mandatory

| SE Class | TID Class | Test Rank | SE Status | TID Status | Type | Reference Datasheet | Case | EDMS | Select List | R2E Lib | R2E Rept | LTSp. Model |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | ToDo *Med.Pr* | TBD (safe/design & vs its use) | TBD (safe/design & vs its use) | Power IGBT | IKW15N120BH6 | TO247 | | | | | |
| | | | | | | | | | | | | |
| 1 | 0 | ToDo *High.P* | TBD (Unknown & to be tested) | TBD (Unknown & to be tested) | Pwr SiC MOSFET | IMW120R140M1H, SCT3160KLGC11 | TO247 | | | | | |
| 1 | 1 | ToDo *Med.Pr* | TBD (safe/design & vs its use) | TBD (safe/design & vs its use) | High P. MOSFET *For/in linear use only* | VS_FC420SA15, APT30M30JLL, APT30M36JLL | SOT227 | | | | | |
| 1 | 1 | ToDo *Low.Pr* | OK (Tested) | OK (Tested) | Med. P. MOSFET | IPD600N25N3-G | DPack | | | | | |
| 1 | 1 | ToDo *High.P* | TBD (safe/design & vs its use) | TBD (Unknown & to be tested) | Low P. N-MOSFET | MGSF1N02L | SOT23 | | | | | |
| 1 | 1 | ToDo *Low.Pr* | OK (Tested) | OK (Tested) | Low P. P-MOSFET | SI3443 | SOT23 | | | | | |
| | | | | | | | | | | | | |
| 0 | 0 | ToDo *Low.Pr* | OK (Tested) | OK (Tested) | PNP Transistor | BCP53-16 | SOT223 | | | | | |
| 0 | 0 | ToDo *Low.Pr* | OK (Tested) | OK (Tested) | NPN Transistor | BCP56-16 | SOT223 | | | | | |
| 0 | 0 | ToDo *Low.Pr* | TBD (Unknown & to be tested) | TBD (safe/design & vs its use) | NPN Transistor | TTC3710B | TO220 | | | | | |
| 0 | 0 | ToDo *Low.Pr* | OK (Tested) | OK (Tested) | PNP Transistor | FMMT591 | SOT23 | | | | | |
| 0 | 0 | ToDo *Low.Pr* | OK (Tested) | OK (Tested) | NPN Transistor | FMMT491TA | SOT23 | | | | | |

### Components Selection

- Sorting candidates
  - Electrical data
  - R2E-reports (if exits)
- Easy access (web)
  - Data summarised for designers / check
  - Datasheet
  - LTSpice Models
  - Sharing our choice for discussion

# Component selection: identify clearly what and why!

## Selecting them carefully and keeping trace of selected criteria!

| Possible Component / References / Alternatives | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Component Manufacturer If Any | Family Reference If Any | Min Voltage Gain [dB] | Typ Input Offset Voltage, Vio @Vcc = 15V, T = 25°C [mV] | Max Input Offset Voltage, Vio @Vcc = 15V, T = 25°C [mV] | Slew Rate @ G = 1 [V/µs] | Unity Gain Bandwidth [MHz] | Factory lead time [Weeks] | Stock from other distributor | Rating 1=keep 3=drop | Reasons for choosing the component | Previous R2E, FGClite, BE-CO DCDC use ? | Radiation Testing | Maximum TID reached | Survived ? | Noticeable Effect due to Radiations |
| Texas Instrument | OPA2192IDR | 114 | 0.005 | 0.025 | 20 | 10 | 57 | #N/A | 1 | Ideal high speed AOP. Two AOP in one SO8! Medium power consumption, high speed (10MHz), and ultra low offset. | | PSI 10-2016 | 750 | Yes | Ibias decreased to -800pA, one SET (larger than 100mV longer than 100ns) observed, no gain degradation |
| Texas Instrument | OPA2196IDR | 114 | 0.025 | 0.1 | 7.5 | 2.5 | 56 | #N/A | 1 | Not tested yet. Higher offset, slower and less bandwidth than OPA2192 but cheaper, very low consumption. | | #N/A | | | |
| Texas Instrument | OPA2134UAE4 | 104 | 0.5 | 2 | 20 | 8 | 35 | 8881 | 1 | Good behaviour under radiation, medium offset, relatively high consumption, but high driving capability regarding ouptut impedance, which stays very low vs frequency and gain. | | PSI 06-2013 | 500 | Yes | Vout drifted by 0,1%, Ibias variation within uncertainty of measurement, no SET (larger than 100mV longer than 100ns) |
| Texas Instrument | OPA2991 | 109 | 0.125 | 0.78 | 21 | 4.5 | 48 | 1260 | 1 | Newer equivalent of TL052-ACD. Medium offset, not tested vs radiation. Medium offset, medium consumption, medium speed. MEDIUM AOP in all criteria. Could be interesting to evaluate it. | | #N/A | #N/A | #N/A | #N/A |
| Texas Instrument | INA2128UG4-T | [1;10 000] | 0,01 + 0,1/Gain | | 4 @ G = 10 | 1.3 | 8 | | 1 | Expensive instrumentation amplifier, could match our needs, can withstand 500Gy. | | PSI 06-2013 | 500 | Yes | Vout stable, Ibias from a few nA to 150nA at 400Gy, no SET (larger than 100mV longer than 100ns) |

**Electrical critical parameters**

**Selected? Why?**

**Ease access to radiation test & conclusion!**

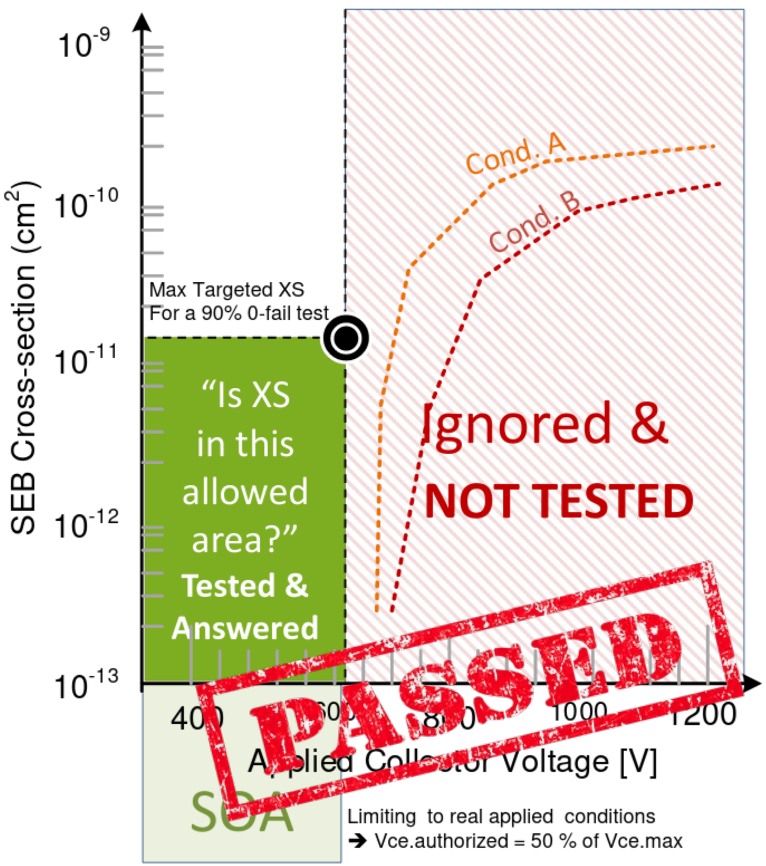
# Component qualification or “verification”

## Minimize the component batches!

- Identify batches (try) & limit them
  - Batch ID: Bobbin, date code
  - Limit them: Buy the whole quantity in one go
- Each cpt batches = 5xmin DUT tested.
  - This is not theoretically sufficient, very often!

## Optimizing test effort

- Apply 0-fail test only (weybayes).
- No need / time for full characterization
  - Monitor the - known degrading and with design impact - parameters with cumulative effects



# Design paths: Single Event

## Single Event is Go – No Go exercise

# Component immune to Single Event is a … good start ;-)

## Component used in the design:

- Use them in their known R2E SOA
  - 50% (at least) voltage use on Mosfet or IGBT (SEB), R-C filtering applied (SET), moderate negative mosfet gate levels (SEGR).
- Use only components qualified through Charm or PSI test campaign
  - Use / Profit from RADWG and CERN facilities!
  - **No single event observed is required at least under converter specific operation mode.**

# Design paths: Dose

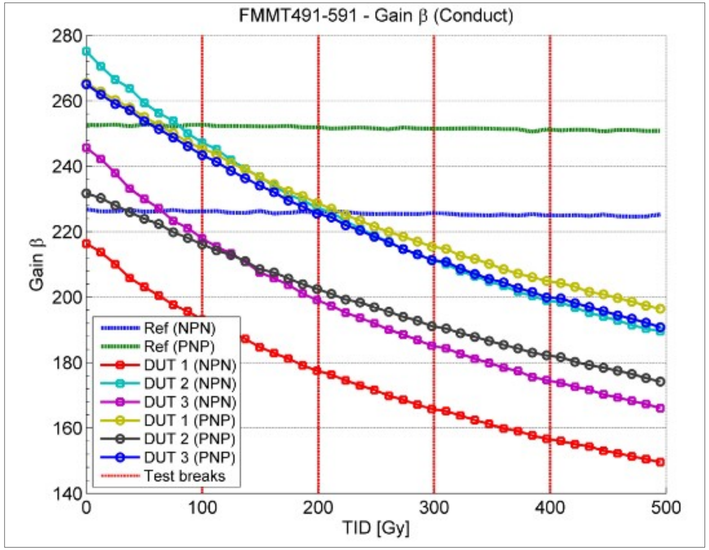
**Reaching 500 Gy is coping with degradation!**

# Dose impact on systems

Dose effect

## Reaching 500 Gy for a power converter is a challenge:

- Don’t use component not able to operate up to 500 Gy !
  - These components are simply rejected ;-)
  - Change the function / electronics schematics, or choose another reference if possible.
- Adapt your design to known & measured component degradation when required
  - Bipolar gain degradation, Vcesat modified
  - MOSFET treshold decrease
  - Component leakage current
  - Consumption increase
  - Precision degradation (voltage reference)



# General design rules vs dose impact

Design Path

## Choose designs not - dose sensitive - per nature

- Ex: Aux power supplies (low power) are 50Hz transformer + Linear regulator.
- Ex: High frequency IGBT drivers chosen design is magnetics cpt based
  - Not using optocoupler (DD-sensitive) or nor specific chips, nor DC-DC, full of unknown COTS

## Choose / adapt design able to cope with component degradation

- Ex: 4-Quadrant Linear Stage can handle very well Mosfet Vgs threshold variation

## Anticipate dose effect through simulation

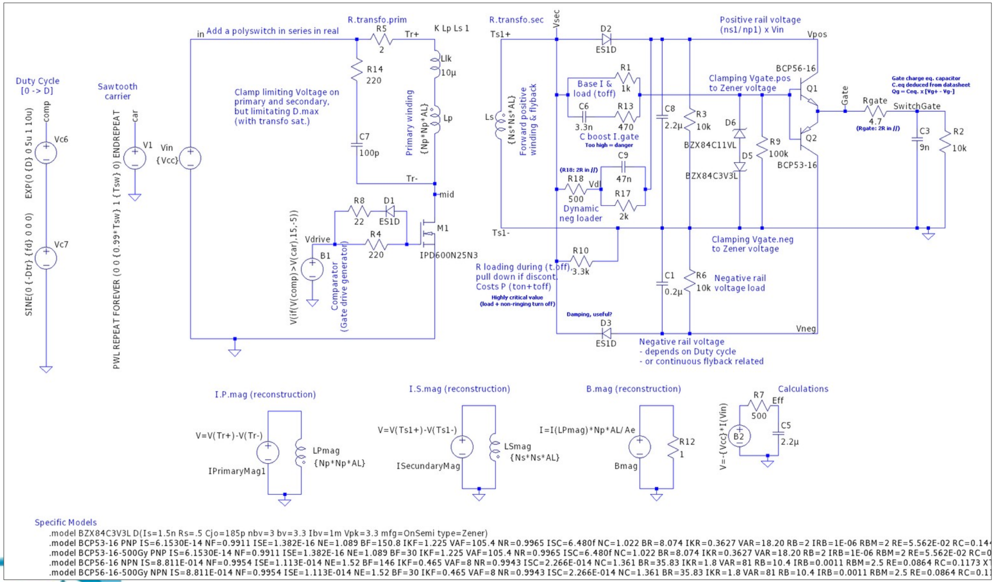
- Any part is simulated to check the design suitability vs component degradation
- High accuracy level of simulation is required with detailed component models
  - Sensitive components can be trimmed for simulating dose effect!

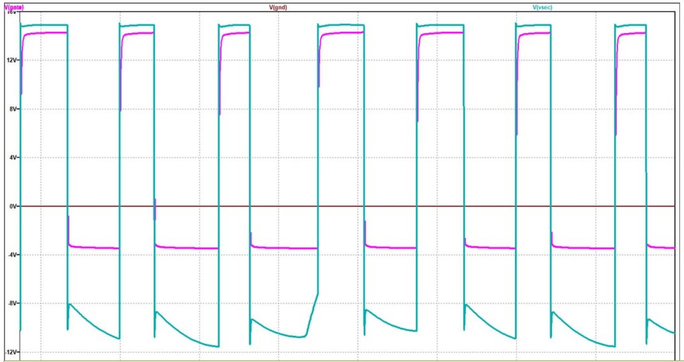
# Simulating Radiation Effects: example - 1

Example-1

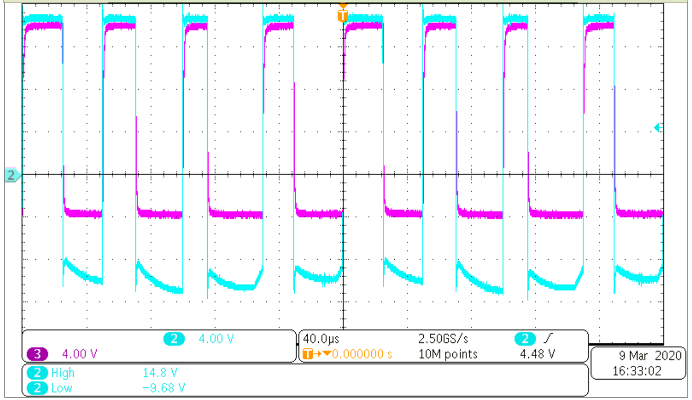
## IGBT driver is a critical part of the converter

- It must work at high frequency, allowing to trim VGS.gate ON threshold, but also OFF one.
- Any malfunction (SE, dose effect induced) on this part would lead to catastrophic IGBT damage.




**Difficult to guess which is simulation or board curves!**





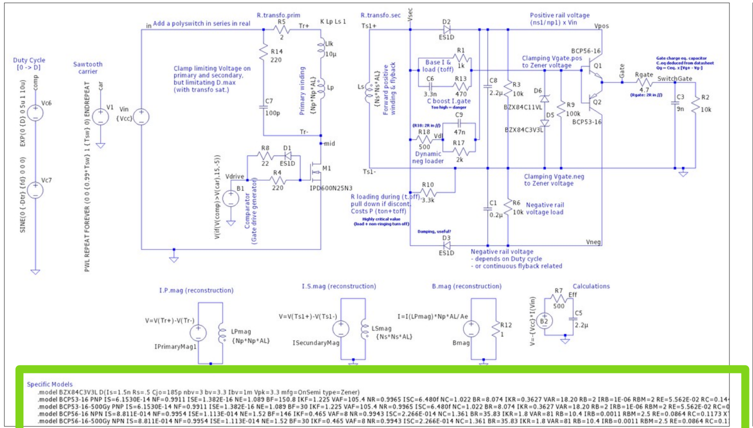

HiLumi HL-LHC PROJECT

# Simulating Radiation Effects: example - 1

Example-1

## Very Flexible Simulation – **Radiation Effect Included!**

- From component fine analyse, a 500 Gy model is injected in simulations



```
# EDMS document: https://edms.cern.ch/document/2437567/
# One model intends to represent the degradation of the component under irradiation
# revision date:2021-01-25 - VBE degradation added
                2020-11-10 - creation
# 500Gy model:
# > HFE degradation:  125 vs 75        BF = 30 (see EDMS 1583310 - High IC. & EDMS 1171985)
# > VCE sat increase: 170 mV vs 155 mV XX = XX (see EDMS 1583310 - High IC. & EDMS 1171985)
# > VBE degradation:  none             XX = XX (see EDMS 1171985 page 4)

.MODEL BCP53-16 PNP IS=6.1530E-14 NF=0.9911 ISE=1.382E-16 NE=1.089 BF=150.8 IKF=1.225 VAF=1
BR=8.074 IKR=0.3627 VAR=18.20 RB=2 IRB=1E-06 RBM=2 RE=5.562E-02 RC=0.1449 XTB=0 EG=1.11 XTI
TF=8.666E-10 XTF=1.231 VTF=3.008 ITF=0.4581 CJC=5.264E-11 VJC=0.6591 MJC=0.4533 XCJC=0.4401
FC=0.9427 Vceo=80 Icrating=1 MFG=Philips
.MODEL BCP53-16-500Gy PNP IS=6.1530E-14 NF=0.9911 ISE=1.382E-16 NE=1.089 BF=30 IKF=1.225 VA
BR=8.074 IKR=0.3627 VAR=18.20 RB=2 IRB=1E-06 RBM=2 RE=5.562E-02 RC=0.1449 XTB=0 EG=1.11 XTI
TF=8.666E-10 XTF=1.231 VTF=3.008 ITF=0.4581 CJC=5.264E-11 VJC=0.6591 MJC=0.4533 XCJC=0.4401
FC=0.9427 Vceo=80 Icrating=1 MFG=Philips
```

Specific Models

```
.model BZX84C3V3L D(Is=1.5n Rs=.5 Cjo=185p nbv=3 bv=3.3 Ibv=1m Vpk=3.3 mfg=OnSemi type=Zener)
.model BCP53-16 PNP IS=6.1530E-14 NF=0.9911 ISE=1.382E-16 NE=1.089 BF=150.8 IKF=1.225
.model BCP53-16-500Gy PNP IS=6.1530E-14 NF=0.9911 ISE=1.382E-16 NE=1.089 BF=30 IKF=1.225 VA
.model BCP56-16 NPN IS=8.811E-014 NF=0.9954 ISE=1.113E-014 NE=1.52 BF=146 IKF=0.465
.model BCP56-16-500Gy NPN IS=8.811E-014 NF=0.9954 ISE=1.113E-014 NE=1.52 BF=30 IKF=0.465 V
```

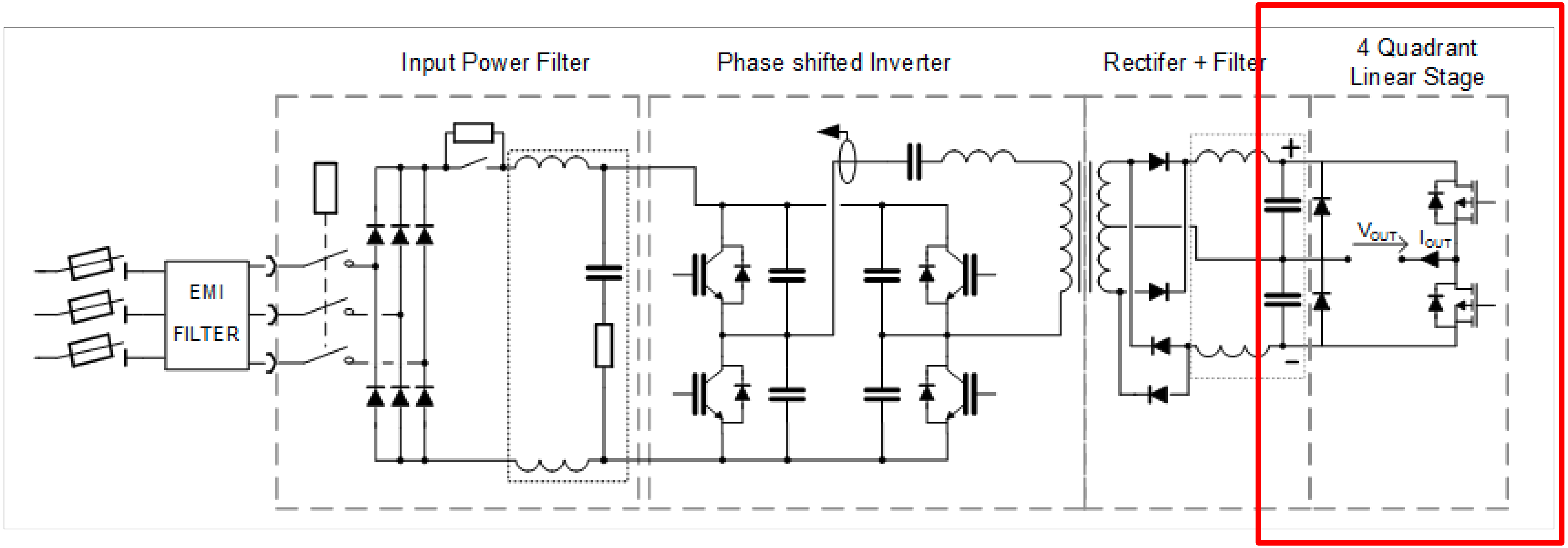
HiLumi HL-LHC PROJECT

# Simulating Radiation Effects: example - 2

Example-2

## Converter 4 quadrant linear mode output stage

- Heart of the converter (energy, dynamic performances in 10's kHz range)




Key part of the converter!

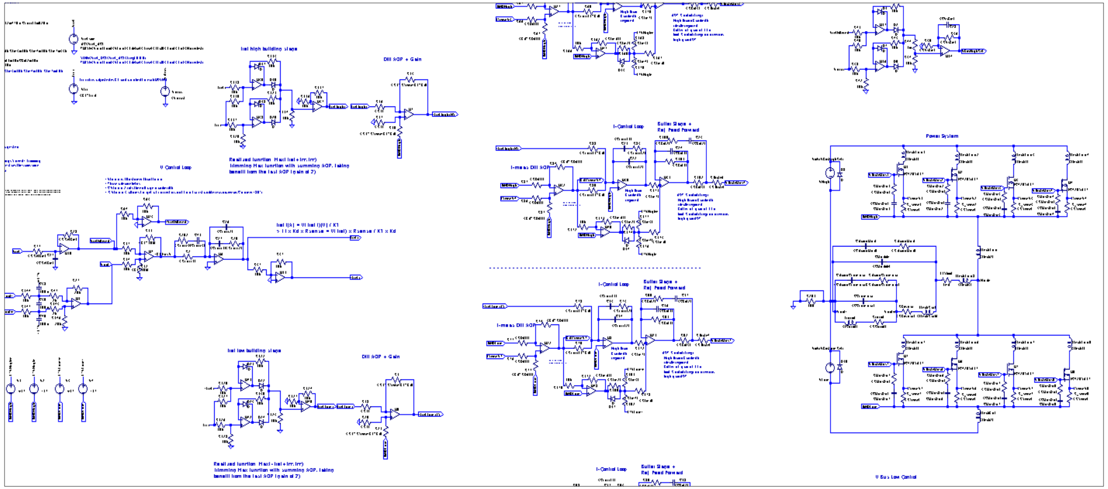
# Simulating Radiation Effects: example - 2

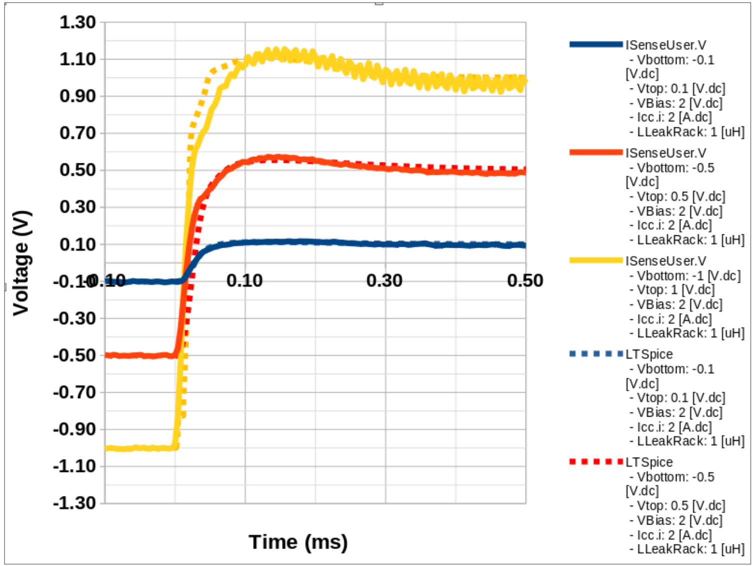
Example-2

## Very Accurate Simulation is required

- Systems & components are simulated up to a quasi-perfect match vs real board.

High Power 4-quadrant Linear Stage






## Specific Models

```
.model APT30M36JLL VDMOS (mtriode=300m Rg=0.1 Kp=45 Lambda=30m Vto=5.39 Cgdmin=20p Cgd
.model APT30M30JLL VDMOS  (mtriode=450m Rg=0.1 Kp=30 Lambda=75m Vto=5.05 Cgdmin=20p Cg
.model FC420SA15 VDMOS (mtriode=1 Kp=25 Rg=.1 Lambda=500m Vto=4.47 Cgdmin=40p Cgdmax=3
```

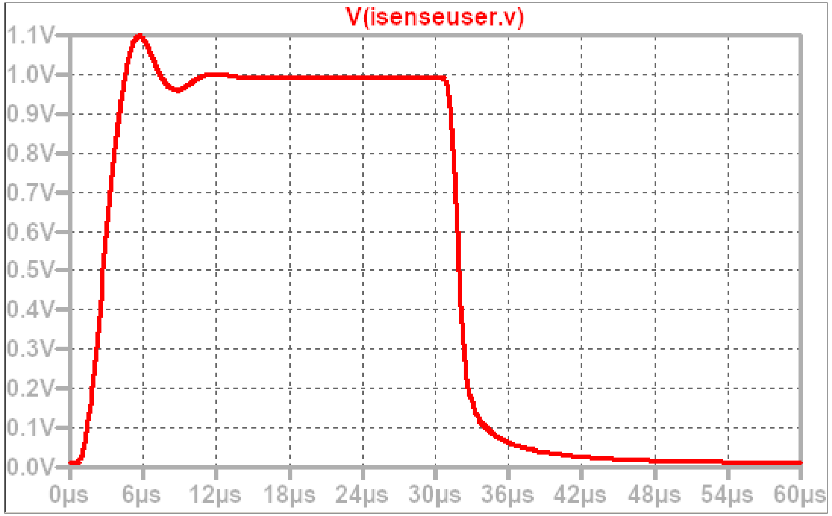
**Very good fit, involving *custom made* power Mosfet Model, (non-linear component)!**

Example-2

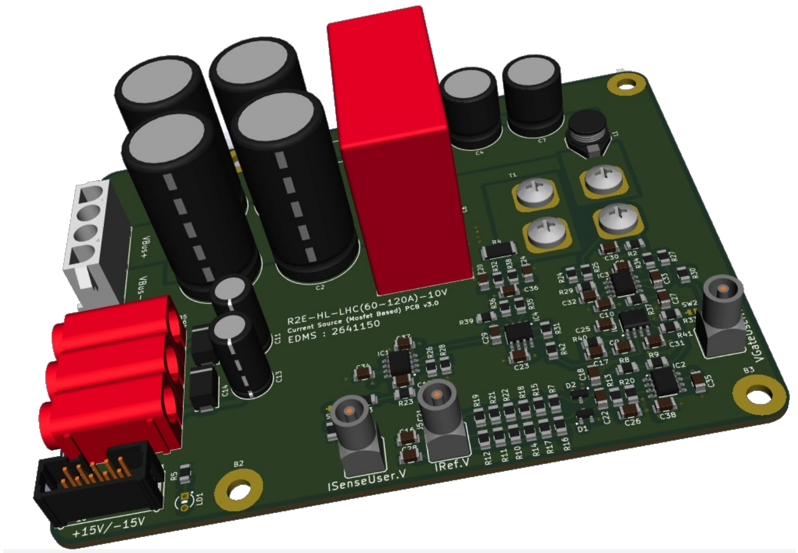
# Simulating Radiation Effects: example - 2

## Evaluating dose effect on Mosfet, adjusting its model vs dose

A test board was designed controlling a Power Mosfet *on the edge*, to observe the radiation effect on very deep parameters of the mosfet, impacting our linear control, and converter stability.




Mosfet current: looking **for overshoot!**

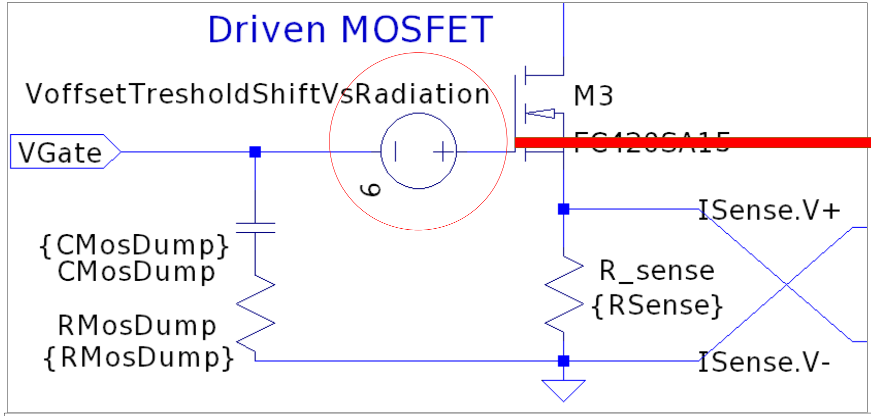


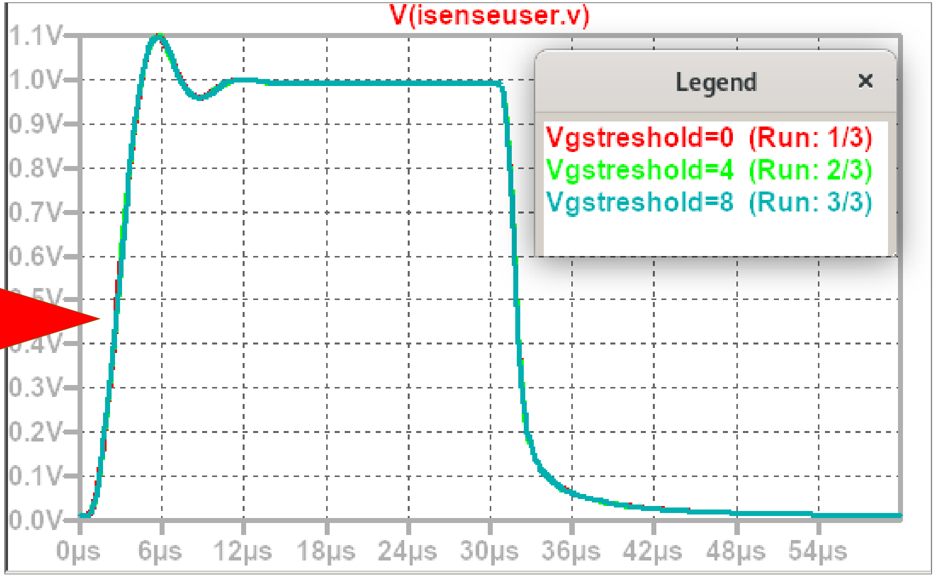
# Simulating Radiation Effects: example - 2

Example-2

## Evaluating dose effect on Mosfet, adjusting its model vs dose

Our overall control is known to be non sensitive to MOSFET Vgs threshold...




### Specific Models

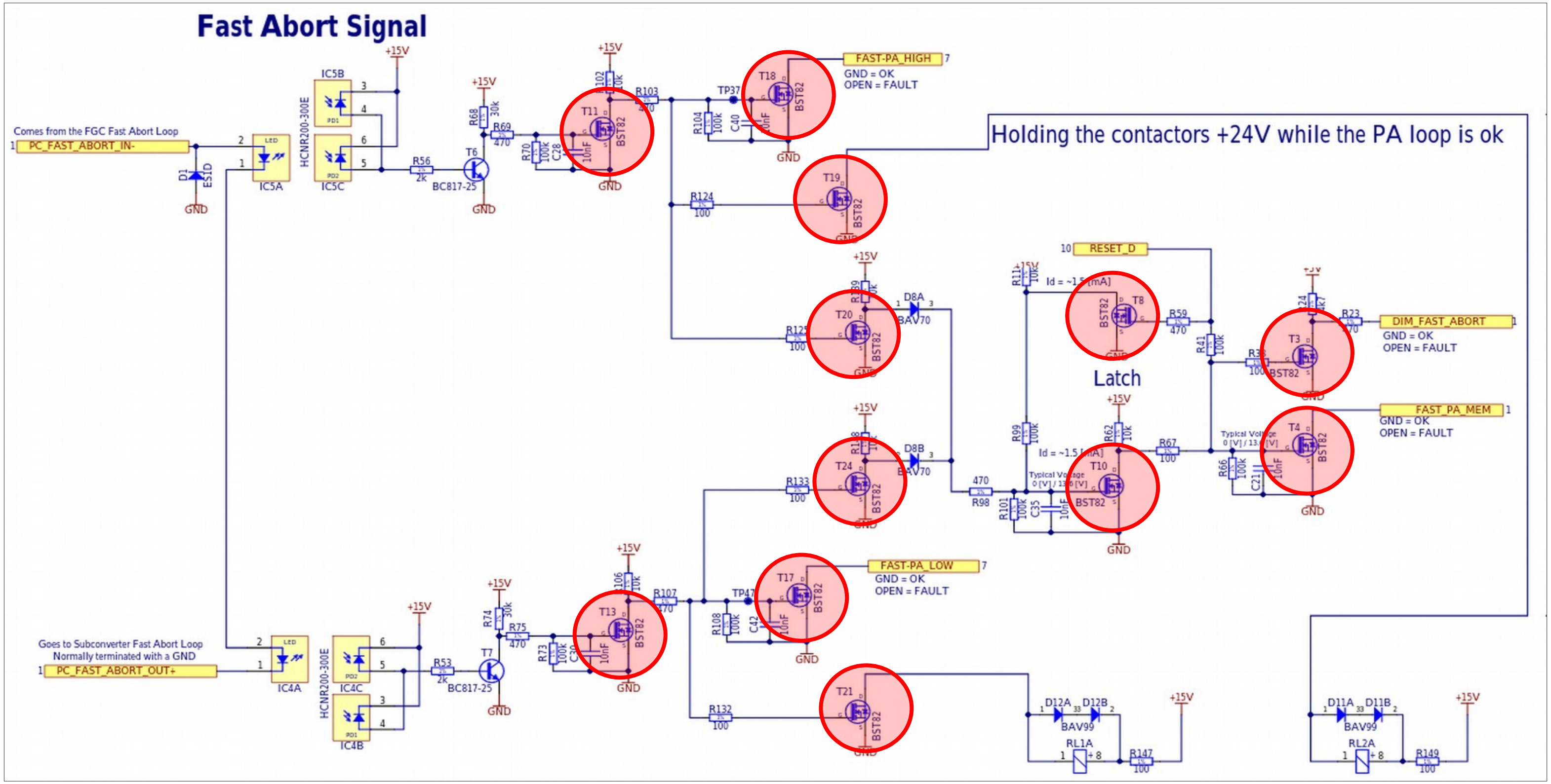
```
.model APT30M36JLL VDMOS (mtriode=300m Rg=0.1 Kp=45 Lambda=30m Vto=5.
.model APT30M30JLL VDMOS  (mtriode=450m Rg=0.1 Kp=30 Lambda=75m Vto=5
.model FC420SA15 VDMOS (mtriode=1 Kp=25 Rg=.1 Lambda=500m Vto=4.47 Cgd
```

… a test (2021-end) @ CERN COBALT 60 will allow adjusting mosfet model vs dose !

# Dealing with specific cases

## Case of Very High Occurrence in the design = SOT23 Low Power Mosfet

Example-3



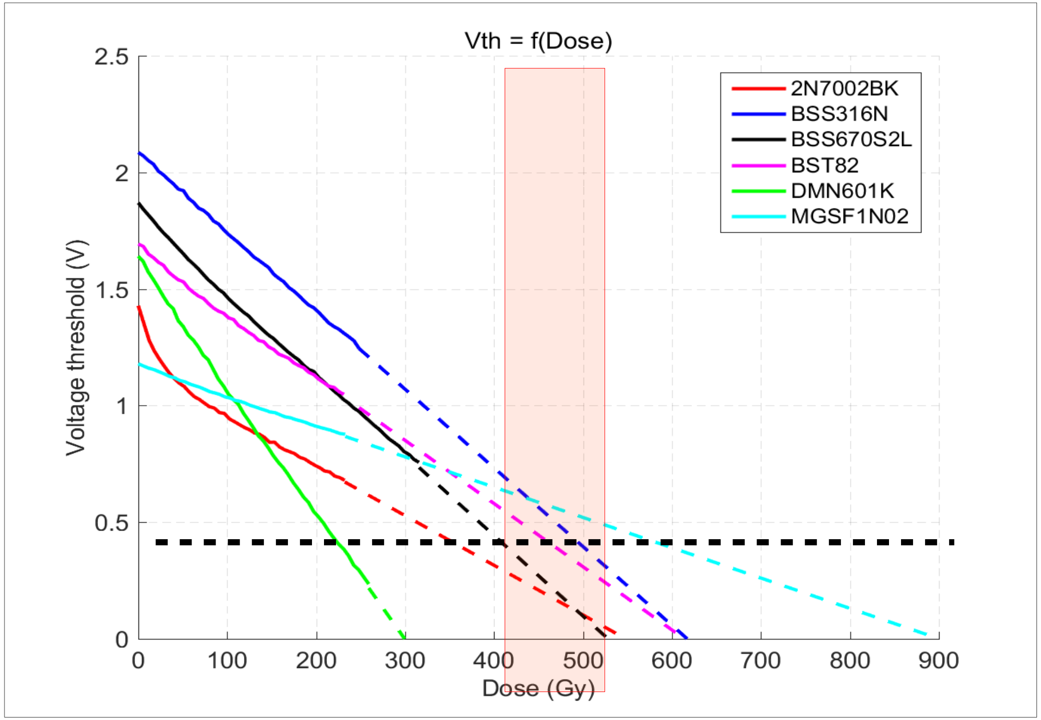

**DOSE Sensitive component used 50..60 times in each module!**

# Dealing with specific cases

Example-3

## Case of Very High Occurrence in the design = SOT23 Low Power Mosfet

- VGS threshold starts to be critical above 400 Gy!



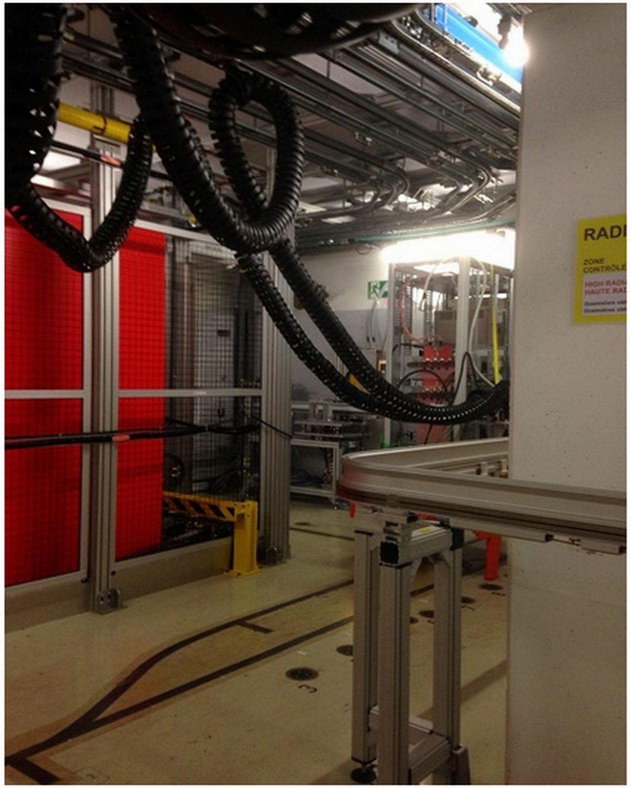

**Still looking for a MGSF1N02 killer… but didn't find it yet!**

**Mitigation**

- When possible, bipolar is used (consumption cost!)
- Gate is biased at 3.3 V (not more) if ON all the time.
- Ensure gate is negative biased (comparator output) whenever possible.

# Final test phase

# Power Converters final qualification step



*Converters will be tested at CHARM as complete unit.*

# Power Converters final qualification step

**Many modules are foreseen for Charm test**

- After converter prototype phase already
  - As soon as possible
  - Testing modules (low weight, air cooled).
- Several pre-series to be tested at Charm
  - Giving some statistics (5x modules at least)
  - Sufficient for Dose verification:
    - 5 converters surviving 500 Gy dose gives a strong design validation (end of life phenomena)
  - Sufficient for validating the converters vs SE:
    - Would allow to reach 9E-13 cross section @ 90%
    - Can verify down to 1 max dump radiation failure for all new 120A converters (92 converters) for ex.

# Conclusion

# Conclusion

## Success in R2E design is & stays based on

- Understanding where / what are the threads
  - Updated LHC radiation levels
- Choosing correct components in adequate / adapted design
  - Rely on R2E component database (thanks RADWG)
  - Rely on enhanced / qualified designs (with simulations including dose degradation - new)

## Focusing on Qualifying the right components in the right facility

- Co60, CHARM, PSI availability is a key point

## Testing final systems

- Nothing beats a full system having pass CHARM test!

***Thank you for your attention***

CERN

# Playing with banners

Starting

Injectors

HL or LHC

Racks overview