

LHC POWER CONVERTERS, THE PROPOSED APPROACH

CERN - Chamonix 2010

Yves Thurel

*with help from Quentin King, Valérie
Montabonnet, Jean-Paul Burnet,
Markus Brugger, Daniel Kramer*



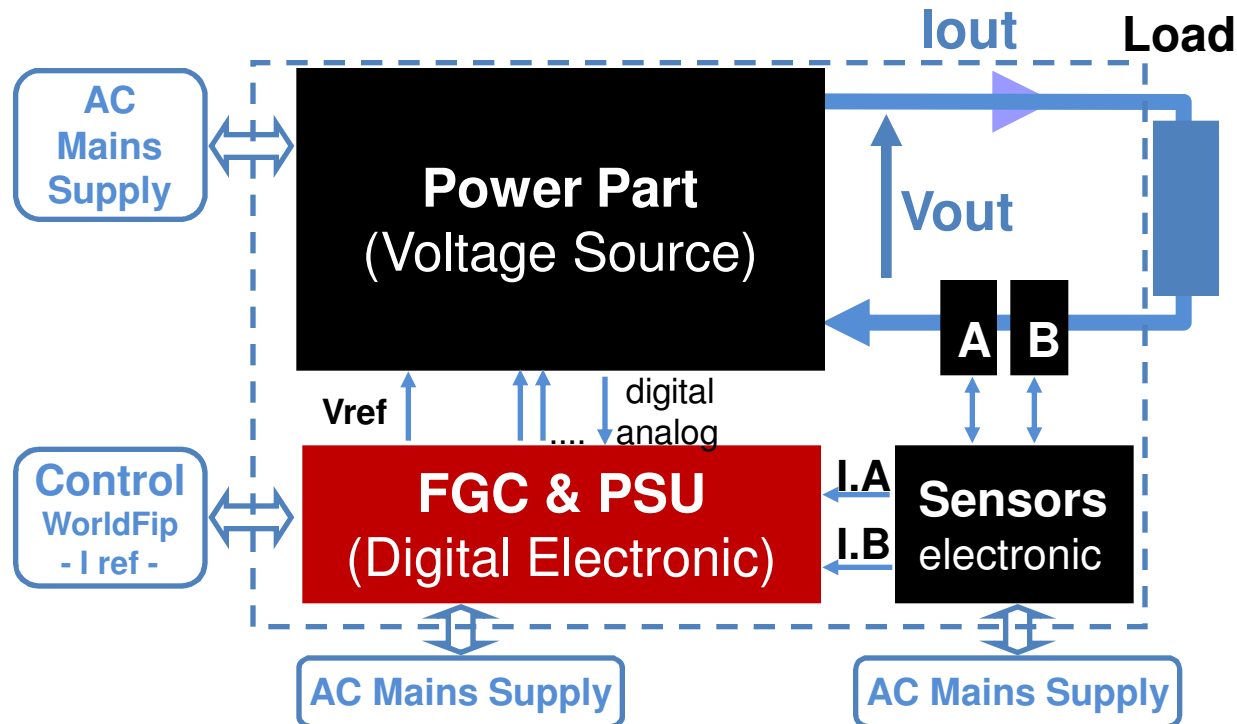
- 1. POWER CONVERTER OVERVIEW**
- 2. RADIATION TESTS RESULTS**
- 3. PROJECTIONS TO THE LHC MACHINE**
- 4. CONCLUSION**

1. POWER CONVERTER OVERVIEW

CONVERTER ARCHITECTURE

CONVERTER DESIGN: FUNCTIONS

- All highly sensitive devices are concentrated in FGC thanks to CERN choices



■ Design not using highly radiation critical components (in LHC case)

■ Design using known sensitive components (RAM, CPU, DSP...)

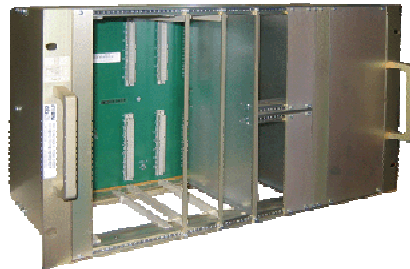
WHAT IS A POWER CONVERTER

■ CONVERTER DESIGN: HARDWARE

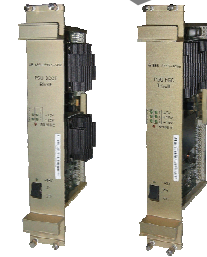
Control Part

- Sensitive devices
- Small size
- Radiation Test is relatively easy

Electronic Chassis



PSUs



Digital Cards: FGC



Sensor Part (DCCTs)

- Rad non-sensitive analog electronic
- Rad. Safe by design

DCCT 60A & 120A



DCCT 600A



DCCT 4..8kA



Power Part

- Lot of components
- Medium to XXL size
- Radiation test is only feasible for low power (<120A)

LHC60A-08V



LHC4..8kA-08V



CONVERTERS MANUFACTURED

▪ LHC CONVERTERS VS RADIATION [2000-2001]

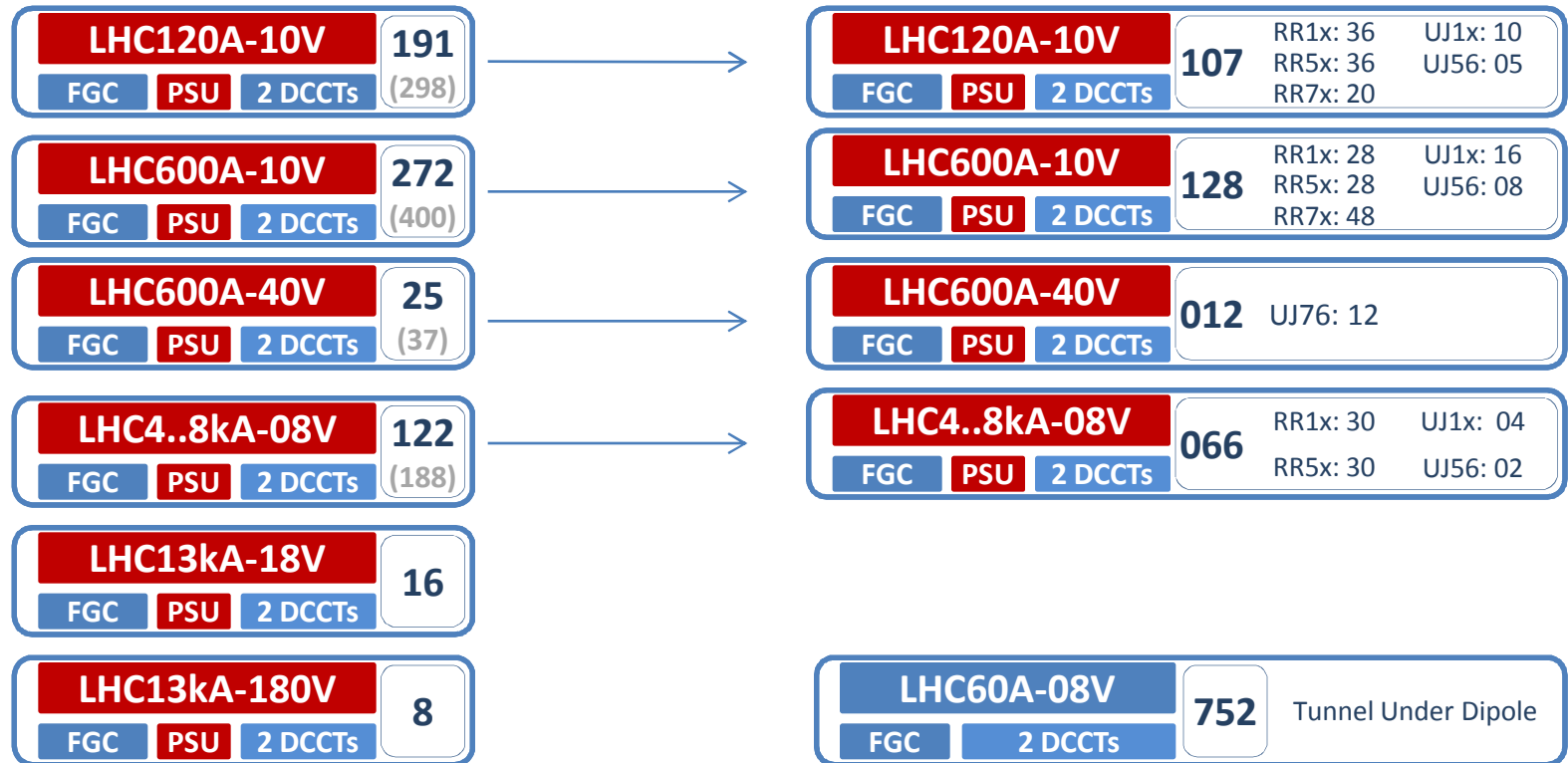
- Rad Tolerant Design *or* standard Design with low Rad sensitivity (safe components)
- Standard Design *and* Rad sensitivity unknown (too many components, sub-assemblies...)



CONVERTERS INSTALLED

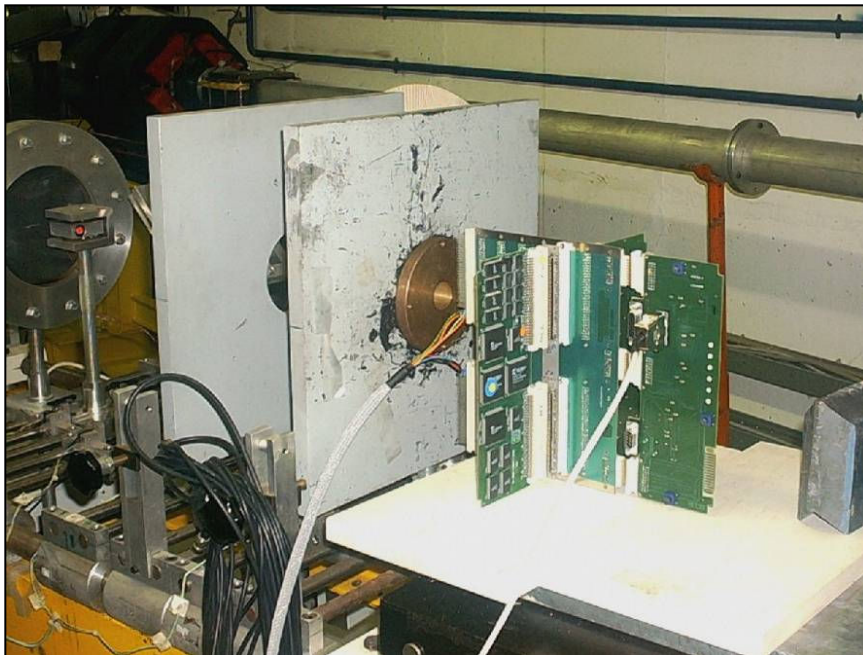
▪ LHC CONVERTERS VS RADIATION [2010]

- Rad Tolerant Design *or* standard Design with low Rad sensitivity (safe components)
- Standard Design *and* Rad sensitivity unknown (too many components, sub-assemblies...)



Radiation Risk

2. TE-EPC RADIATION TESTS



TE-EPC Rad-Team

- Sylvie Dubettier
- Vincent Barbet
- Laurent Ceccone
- Philippe Semanaz
- Pierre Martinod
- Quentin King
- Yves Thurel



CERN Rad-Team

- Thijs Wijnands
- Christian Pignard

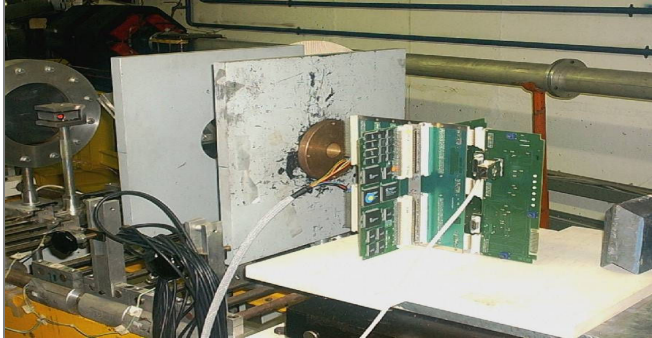


**Real Manpower Effort &
A lot of hours testing...**

RADIATION TESTS

▪ RADIATION SUSCEPTIBILITY TESTS DONE ON:

LOUVAIN (2003 - FGCs)



60 MeV components tests

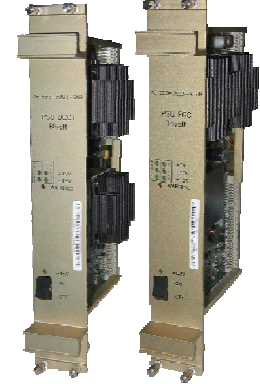
LHC60A-08V



FGC



PSUs

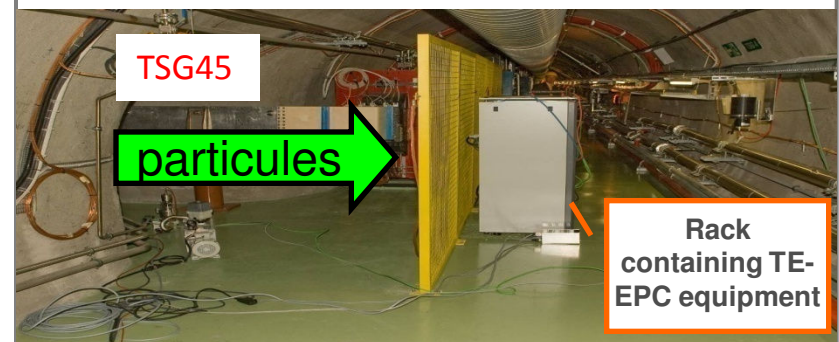


PROSPERO (2009 - FGCs)



1MeV validation tests

CNGS (2008..2009 – FGCs, 60A, PSU)



LHC-Environnement System Test

FGC / FGC PSU RESULTS

■ WHAT DID WE LEARN ON FGC & PSU

■ THE GOOD

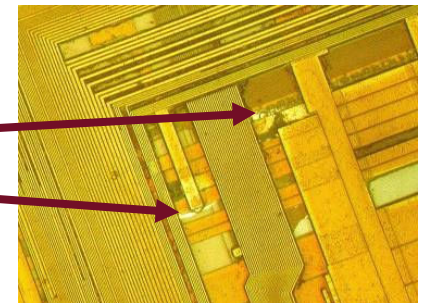
- FGC Rad-tolerant hardware design from beginning is OK
- FGC Very well tested: CNGS, Prospero, TCC2, Louvain
- PSU are not SEE sensitive and their T.I.D limit = 40 Gy

■ THE BAD

- Xilinx CPLD used 11x in one FGC was chosen after good results in Louvain 2003
- **BUT** CNGS showed that higher energy particles can lead to
 - recoverable latch-ups (converter stops)
 - and once a definitive burn-out.

■ THE UNKNOWN

- One Xilinx CPLD died during CNGS tests, where up to 60 CPLD were tested in total. Was it isolated case?

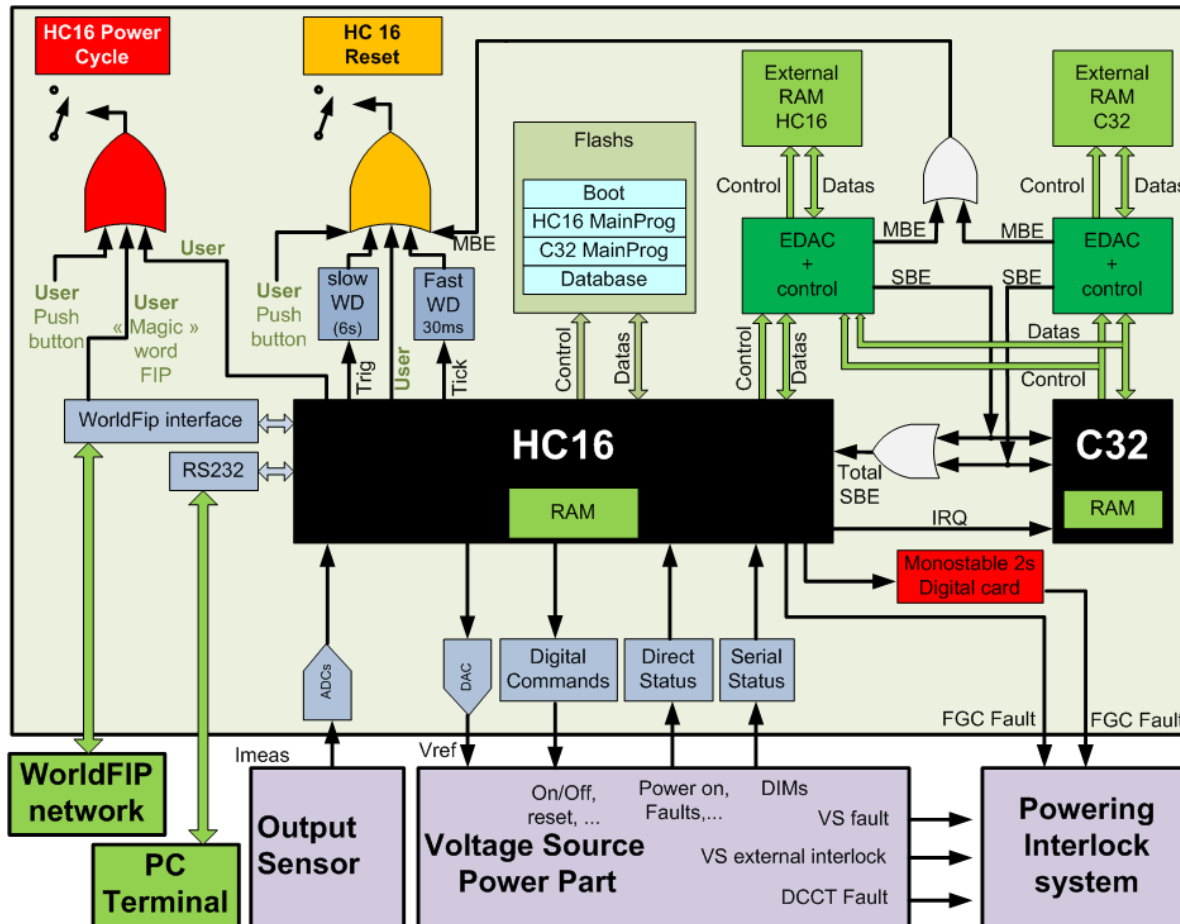


■ FGC Controller susceptibility

- T.I.D. Limit **60Gy** (40Gy for PSU) which is > 20 years in 95% case
- S.E.E cross section **FGC cross section = $2 \cdot 10^{-11} \text{ cm}^2 \text{ E} > 20 \text{ MeV}$**

FGC RADIATION DESIGN

OVERVIEW OF FGC MITIGATION TECHNIQUES USED



Main Processor: HC16
• internal RAM **not** used

DSP Co-Processor C32
• internal RAM **not** used

Memories
• **SEE Optimized**
• **Adequate** Technology
• **EDAC** Corrections

Power Cycle
• WordFip Magic (long packet to **remotely** power cycle FGC)

Reset
• Automatic Reset operation-transparent in case corruption detected is possible (*not yet implemented*)

POWER CONVERTER: LHC60A-08V

■ WHAT DID WE LEARN ON LHC60A-08V

■ THE GOOD

- Rad-tolerant hardware design from beginning is OK
- Power Part is not sensitive to SEE
- SEE is then given by FGC, when T.I.D is given by power part. (50Gy)
- Operation can lose some 60A converters without losing beam



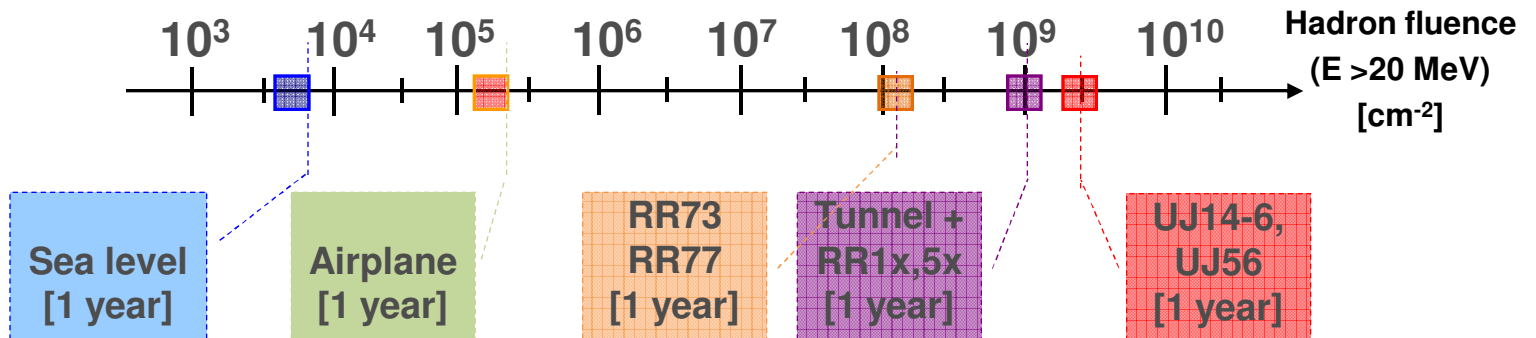
■ Power Converter (FGC + Power Part) susceptibility

- T.I.D. Limit **50Gy** (25 years min for LHC)
- S.E.E cross section **given by FGC**
= 1 recoverable failure every 3-5 days

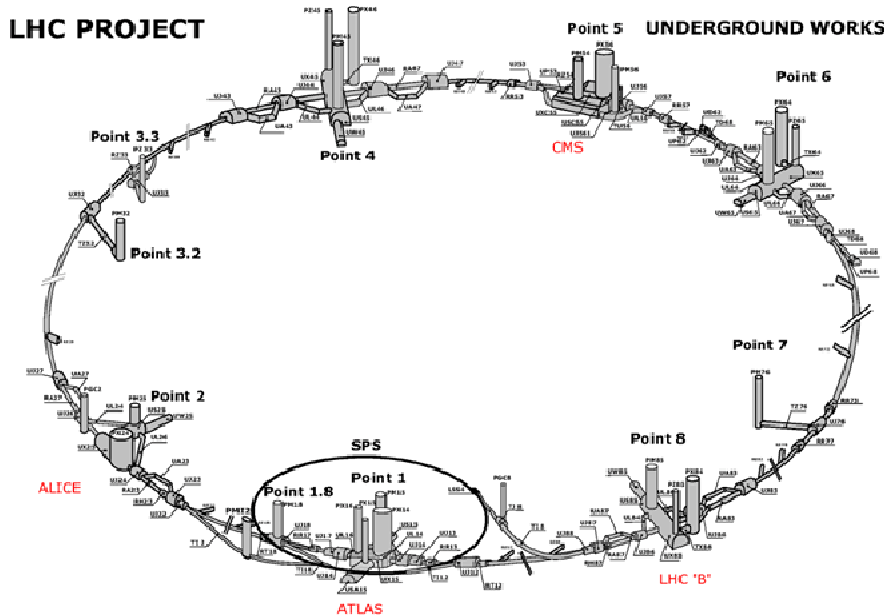
■ Comments

- 0.3Gy/year, with 1 exception: 2-3 Gy/year
- $5.10E9/cm^2/an$ $E > 20MeV$

3. LHC PROJECTIONS



▪ EPC EQUIPMENTS IN LHC POINTS



UJ14, UJ16, UJ56	5.10^9 /[cm ² .year]	045 power converters
Tunnel under dipole:	5.10^9 /[cm ² .year]	752
RR13, RR17, RR53, RR57 ..	1.10^9 /[cm ² .year]	188
RR73, RR77	1.10^8 /[cm ² .year]	68

Considered Safe

All UAs & UJs not listed below (*is it correct?*)

Tunnel

▪ LHC60A-08V (752)

Point 7 – UJ76

▪ LHC600A-40V (12)

➔ relocation

Critical 301 converters

Point 1 & Point 5

▪ LHC120A-10V (87)

▪ LHC600A-10V (80)

▪ LHC4..8kA-08V (66)

Point 7

▪ LHC120A-10V (20)

▪ LHC600A-10V (48)

- **SIMPLIFIED & LIMITED APPROACH FOR HOT POINTS (1,5,7)**

- **The scope: FGC SEE focus ONLY, T.I.D only critical in UJ56**

- Only data on FGC available (Power Part unknown)
- All converters point 1, 5, 7 are considered as critical
- Simplified approach using approximate levels without shielding
 - point 1 + 5: *Fluence: $1..5 \times 10^9$ /cm² / year $E > 20$ MeV*
 - point 7(RR): *Fluence: 2.10^8 /cm² / year $E > 20$ MeV*



- **The result of this approach based only on FGC reliability gives**

- Point 1+5: 1 FGC \Leftrightarrow 1 Power Converter failure every ~ **20 days**
- RR73+ RR77: 1 FGC \Leftrightarrow 1 Power Converter failure every **> 03 years**

- **Comments on the results on FGC reliability**

- FGC does the job.
- Figures are minimum failure rate since power part can / will also fail
- All location with T.I.D higher than 2-3 Gy / year are not compatible with our equipment (FGC + PSU) lifetime (40-50 Gy = 2 Gy x 25 years)

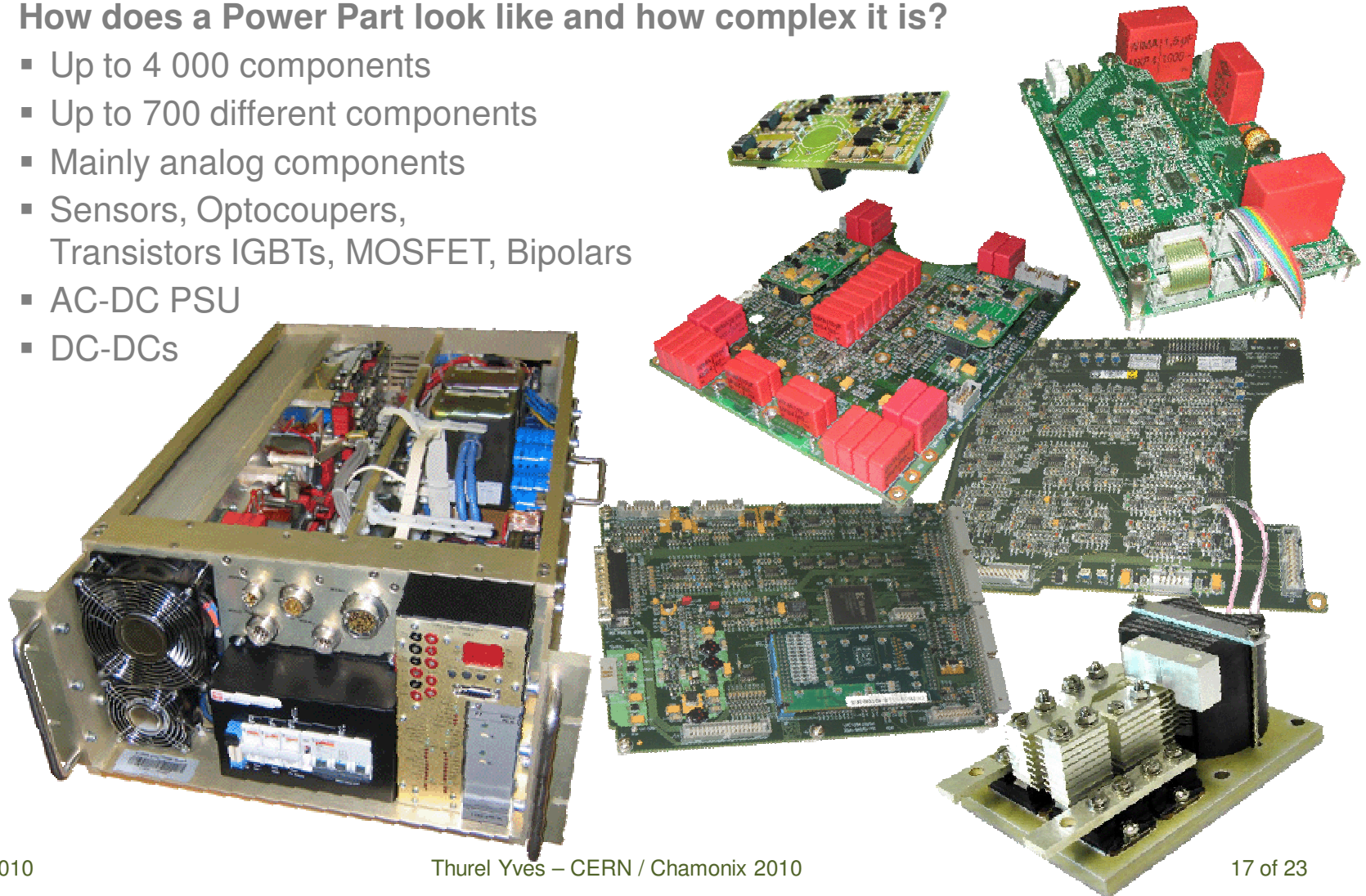
POWER PART OVERVIEW

- **POWER PART CONVERTERS** (VOLTAGE SOURCE WITHOUT CONTROLLER)
 - **THE GOOD**
 - AC CERN Network is a severe environment (Over Voltage rating applied)
 - All very sensitive devices are concentrated in FGC electronics (by Design)
 - Power Part is mainly based on classical analog devices
 - **THE BAD**
 - LHC600A-10V, LHC4..8kA-08V external design. (re-design reaction time : years)
 - Converter power part is hard / impossible to test under radiation (big volume, high number of components, water cooled...)
 - [5V CPLDs] are used in LHC600A, LHC4..8kA-08V
 - LHC120A & DIM card used for diagnostic are based on FGC Xilinx CPLD (NO remote power cycle feature integrated in 120A converter or DIM card)
 - **THE UNKNOWN**
 - A lot of DC-DCs are used in all converters
 - Some integrated devices are used (IGBT drivers, AC-DC power supplies, CPLD...)



POWER PART EXAMPLE

- **POWER PART CONVERTERS** (VOLTAGE SOURCE WITHOUT CONTROLLER)
 - How does a Power Part look like and how complex it is?
 - Up to 4 000 components
 - Up to 700 different components
 - Mainly analog components
 - Sensors, Optocouplers, Transistors IGBTs, MOSFET, Bipolars
 - AC-DC PSU
 - DC-DCs



POWER PART: LHC120A-10V

▪ LHC120A-10V POWER PART (VOLTAGE SOURCE)

- CERN Internal Design
- Design was initially -2002- thought to be rad-tol “compliant” in case of...
- Critical interlock (current leads & earth) identified as **UNSAFE** under radiation, since using same FGC sensitive Xilinx CPLD
 - This CPLD then can represent a real safety hole



▪ TE-EPC POSSIBLE FUTURE ACTIONS

- Rad Test of power unit really needed?
 - Why not to use LHC as a test facility since we can react quickly if...?
- Partial redesigned relatively easily (CERN Design), and rather quick.
 - CPLD Based card will be surely re-designed or modified (to be planned)
- Is non-proactive plan acceptable?
 - Would certainly liberate EPC Manpower
 - Would only cost some months of non-optimum LHC operation mode on low current converters...

POWER PART: LHC600A-10V

▪ LHC600A-10V POWER PART (VOLTAGE SOURCE)

- **External** Design EEI – CIRTEM
- **[5V CPLD] same type used 5x** – no rad. Info
- **A lot of DC-DCs are used**
- **No CPU, No RAM, No DSP, No FPGA**

▪ TE-EPC POSSIBLE FUTURE ACTIONS

- Testing power unit is almost impossible (water cooled converter, too complex design, external design...)
- A rad-tol power converter redesign coupled with Inner Triplet Upgrade
 - $[+/-3000A +/-10V] \Leftrightarrow 6x [+/-600A +/-10V]$ in parallel in a N+1 converter
 - 3-4 years to get COTS rad-tol converters
 - Unit Cost estimation: 30kCHF (LHC converter : 25 kCHF)
→ LHC Rad-Upgrade : 4.2 MCHF (140 Units)



POWER PART: LHC4..8KA-08V

▪ LHC4..8KA-08V POWER PART (VOLTAGE SOURCE)

- **External** Design Kempower
- **[5V CPLD] same type** used 7..10 times – no rad. Info
- **High precision version (Inner triplet) uses Xilinx CPLD based 22 bit sigma delta ADC unit**
- **Not a single DCDC being Used**
- **No CPU, No RAM, No DSP, No FPGA**



▪ TE-EPC POSSIBLE FUTURE ACTIONS

- Testing power unit is impossible
(water cooled converter, too big size, too complex design, external design...)
- Is a redesign realistic: Manpower, cost?
Non Rad-tol Standard Unit price: 75 kCHF
→ LHC Rad-Upgrade > 5 MCHF (70 Units)
- Complete analysis and partial re-design of potentially unsafe cards can be a possible preventive solution, less costly.
→ Will require time and/or manpower.
→ Budget known after 1st analysis only

4. CONCLUSIONS

CONCLUSIONS (1/2)

▪ CONCLUSIONS

- LHC60A-08V: **SAFE & under control**
- LHC120A-10V: **UNSAFE** but limited action can/will correct CERN design
- Question is: Is sleeping mode acceptable?
- LHC600A-10V: **UNKNOWN and potentially CRITICAL**
 - Complete redesign: possible → Inner Triplet Upgrade
 - Possible relocation has to deal with cables voltage drop: 600A-40V can replace a 120A/600A-10V but is **costly**.
(LHC600A-40V = 80kCHF/Unit: replacing all 68 RR7xconverters being relocated with an existing LHC600A-40V = **5.4 MCHF**)
- LHC600A-40V: **SAFE by relocation (action already launched)**
- LHC4..8kA-08V: **UNKNOWN and potentially CRITICAL**
 - Surely the most critical item (LHC need it 100%)
 - Redesign is far from EPC Manpower & Plans
 - Action Possible: Card analysis → card redesign & test
 - Relocation OK if cryo line added (Cable Voltage drop)
 - Inner Triplet Upgrade does not solve RR1&5 situation

▪ CONCLUSIONS

▪ EPC Position:

- We could “survive” 3-4 years, waiting for a civil engineering work upgrade if chosen
- Inner Triplet upgrade project can be used for a double goal (600A-10V redesign)
- Some locations have to be absolutely lowered in terms of radiation
UJ56 is announced at 5 Gy/year, which means majority of our equipments are dead after only 8-10 years.
- Biggest fear is that troubles arrive in some years only (high luminosity) and could make LHC not useable for years!!! (crash program = long reaction time).

▪ EPC Recommendations:

- Our actual power converters should not be placed in areas more than 2-3 Gy/year
- In case converter redesign options are chosen, reaction time is around 4 years
- Relocation options must accommodate cost increase if voltage drop exceeds rating of existing power converters.
- A CERN or Department level service for Rad-Tests of component would improve the efficiency of choosing rad-tol components.