CERN

R2E Annual Meeting 2018

Radiation tolerant developments: Cryogenics

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CERN TE-CRG

Contents

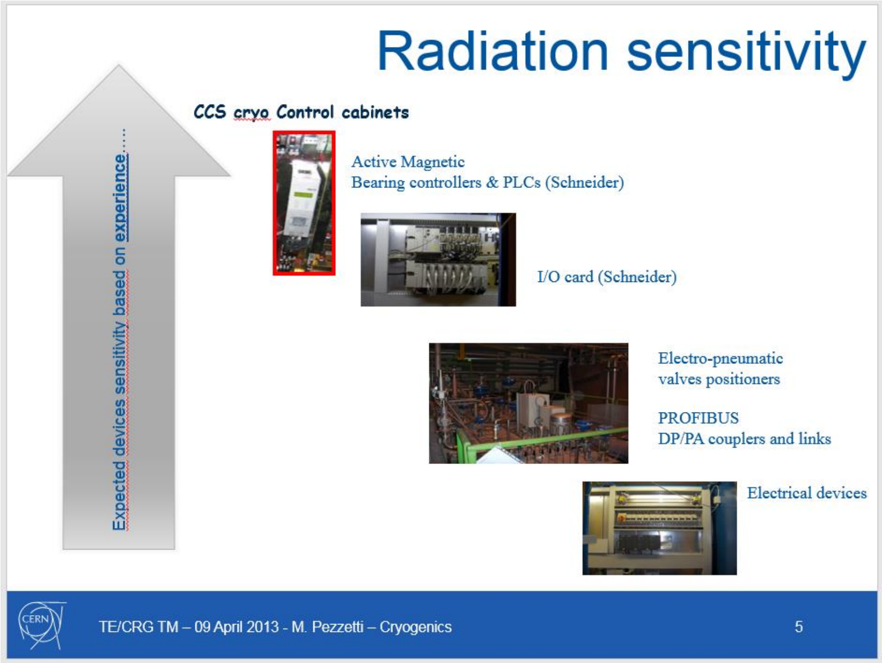
- Industrial/Commercial equipment.
- Rad-hard instrumentation.
    - Radiation hardness of the LHC valve actuators.
- Custom rad-tol electronics.
    - Results from recent tests.
- R2E strategy.

Industrial/Commercial equipment

Commercial equipment in safe/protected areas, mainly:

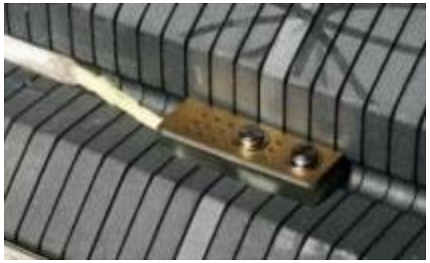
- Industrial Programmable Logic Controllers (PLCs).
- PLC associated components (IO, field electronics, ...).
- Intelligent valve positioner: active electronics.
- Cold Compressor electronics.
- …

- ❖ P4/P8: Already relocated.
- ❖ P2: No relocation required.
- ❖ P6 @ UX65. Low rad levels. No R2E failures ever observed (2015 used as benchmark), no relocation planned.



No relocation foreseen for HiLumi.

Radiation hard Instruments



Qualified or intrinsically rad-hard instruments:

- Temperature sensors (tested @ cold till 3 x 10^{14} n.cm^{-2}).
- Pressure sensors measuring > 1 bar.
- Superconducting level gauges.
- Solenoid valves.
- ………

Valve Positioner:

- Radiation test: Co-60 gamma source.
- Over 10 piezo tested: 1^{st} failure @ 137 kGy TID. Overall test up to 280 kGy.
- In-situ radiation monitoring: lower doses than expected from simulations. *Results in the next slides .*

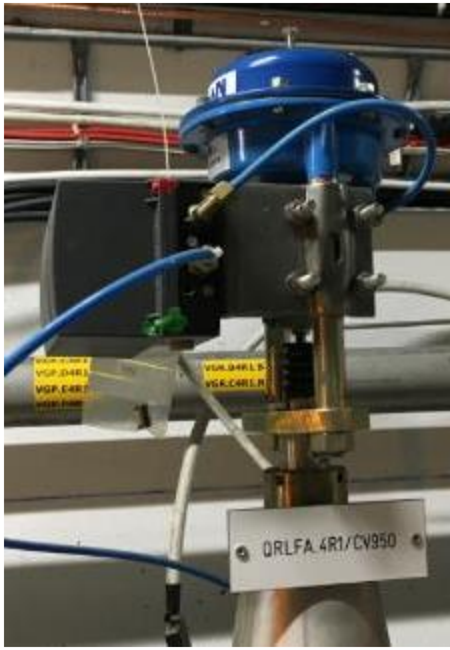
Pressure sensor:

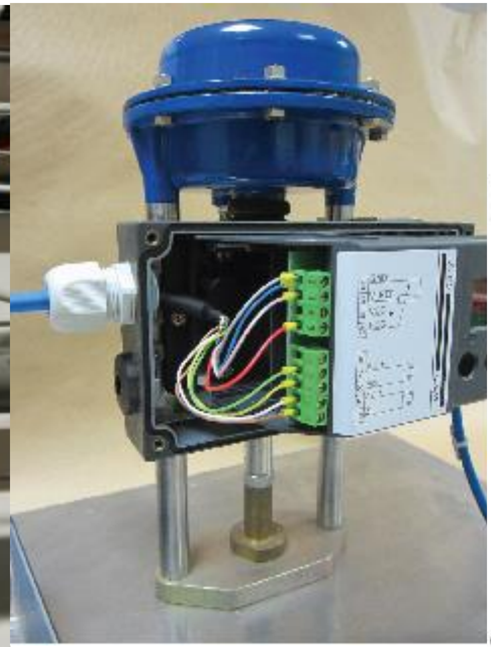
- Low range pressure sensors required by LHC and experiments.
- Qualified supplier: none @ present!
- Candidate devices being evaluated.

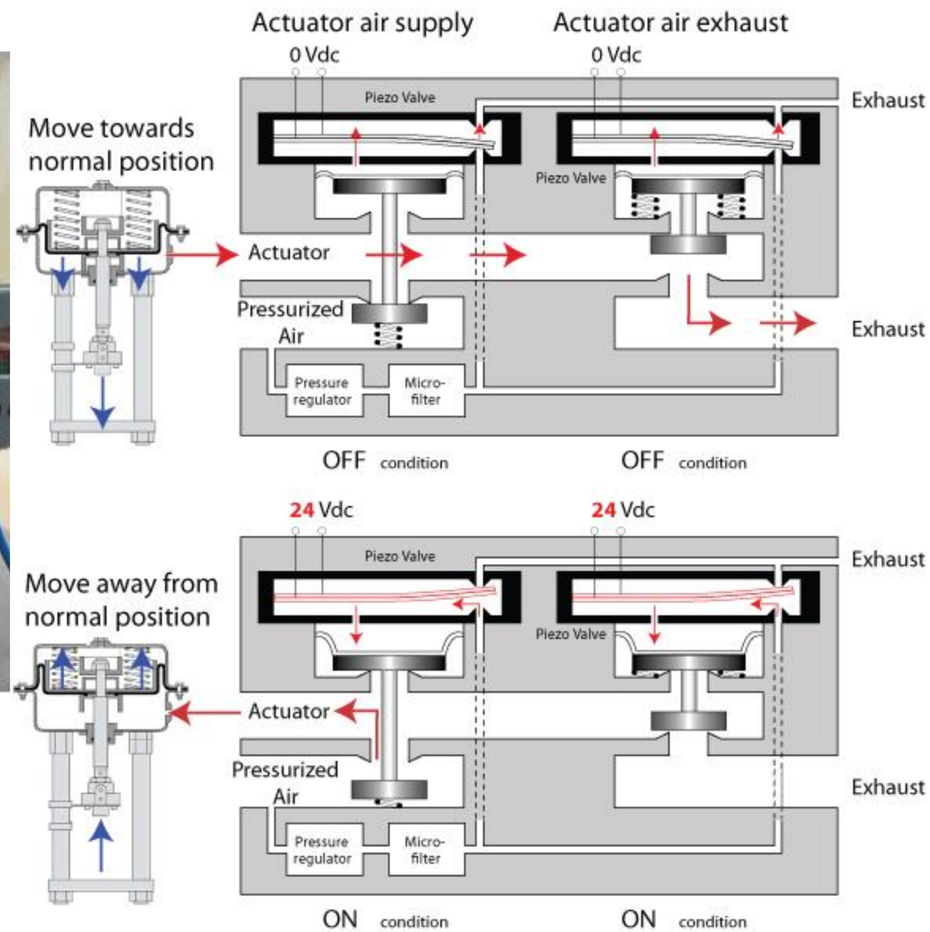
↓

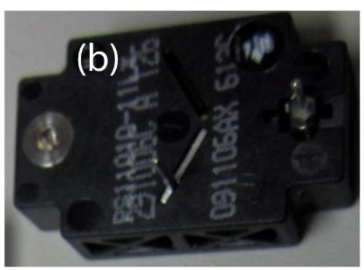
Presentation “Radiation Hardness of Pressure Sensors Suitable to Measure in the 0-100mbar Range”, by Michal Jozef Les on 12 Dec 2018 18:20.

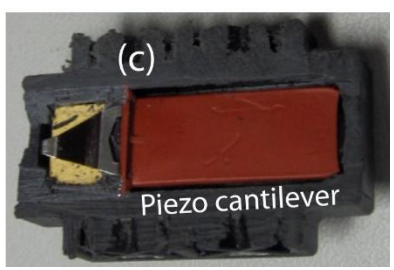
Radiation hardness of the LHC valve actuators





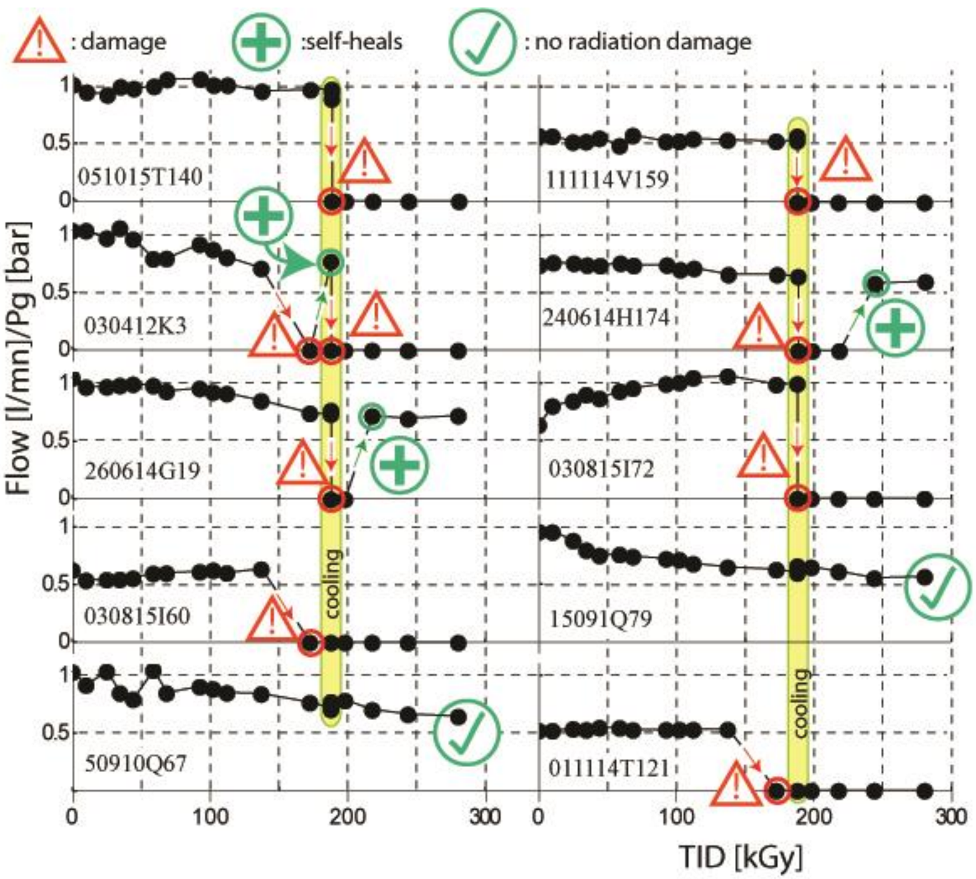






Radiation hardness of the LHC valve actuators

TID [kGy]	0	10	25	34.6	44.2	58.9	68.5	92.7	102.4	112.4
Date	02-May	11-May	15-May	17-May	19-May	22-May	24-May	29-May	31-May	02-Jun
Duration [hr]	-	45	114	158	202	269	313	424	469	515
TID [kGy]	137.4	172.8	188.1	188.1	188.1	188.1	198.3	218.1	244.1	280.7
Date	12-Jun	19-Jun	22-Jun	11-Jul	02-Aug	11-Oct	13-Oct	17-Oct	23-Oct	01-Nov
Duration [hr]	631	793	863	863	863	863	910	1,001	1,120	1,288



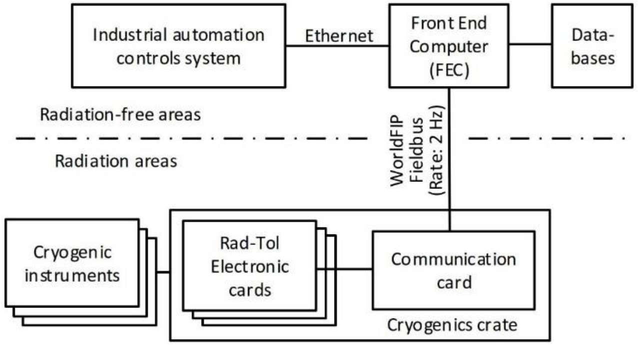
HiLumi radiation estimation shall not exceed 60 kGy for worst location

⇒ Gamma rays dose: SIPART qualified for HiLumi

However is the gamma radiation equivalent to a mixed field that include heavy particles?
60 kGy TID target difficult to reach in CHARM
* Eventually single piezo test in HIRRAD?

Custom rad-tol equipment - The cryogenics crate

The cryogenics crate



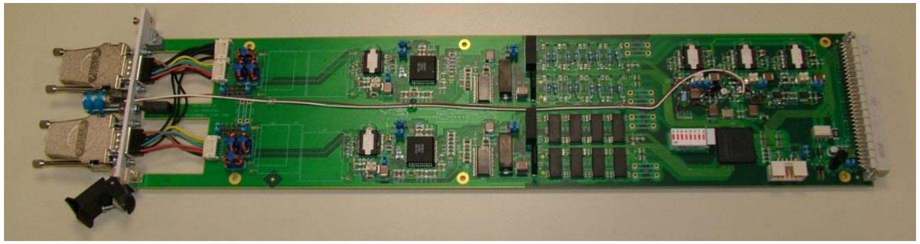
System architecture

For the LHC:

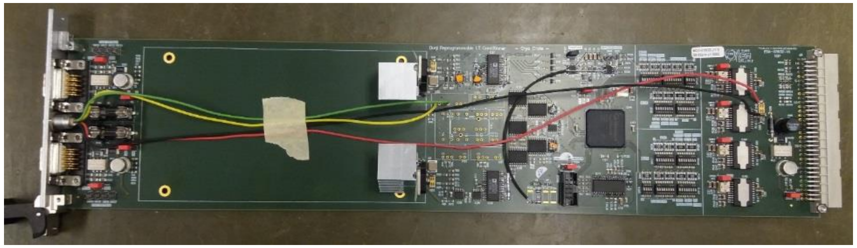
800	WorldFIP crates
Active channels:	
6500	Temperature
800	Pressure
500	Liquid He level gauges
1400	Cold mass heaters
600	Beam screen heaters
1100	Mechanical Switches (I/O)
1050	WorldFIP cards (2100 channels)

- Installed in ARCs (from cell 8), shielded and protected areas.
- All existing designs based on Microsemi antifuse A54SX FPGA (3 kGy).
- Rad-tol target for electronic components > 1kGy.

Cards with Smartfusion2 FPGA 2016/2017/2018



Prototype double-channel temperature card



Prototype double-channel LT card

During 2016 the 4 FPGA versions were explored:

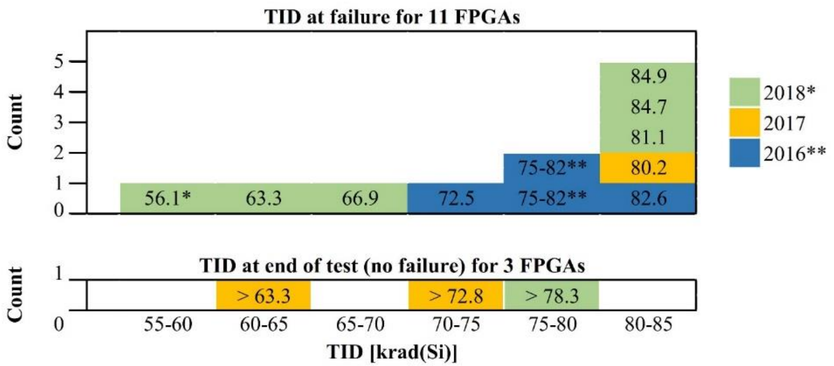
- *Onehot*/Safe, No TMR***
- *Onehot/Safe, TMR*
- *Hamming 8/4***, TMR*
- *Hamming 8/4, TMR with with distant FFs*

**Onehot: FSM encoding with only one "1" bit per state.*
***TMR: Triple Modular Redundancy on FFs only.*
****Hamming 8/4: Double error detect single error correct.*

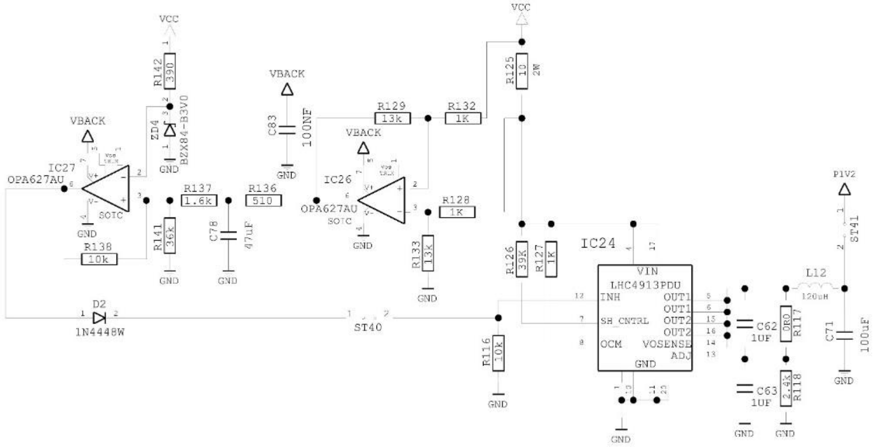
All versions offered 13-bit diagnostics per channel.

3 cards with FPGA code version Hamming 8/4***, TMR

Cards with Smartfusion2 FPGA – Some results



TID results for all cards/campaigns



Anti-latchup circuit to cope with non-destructive SELs.

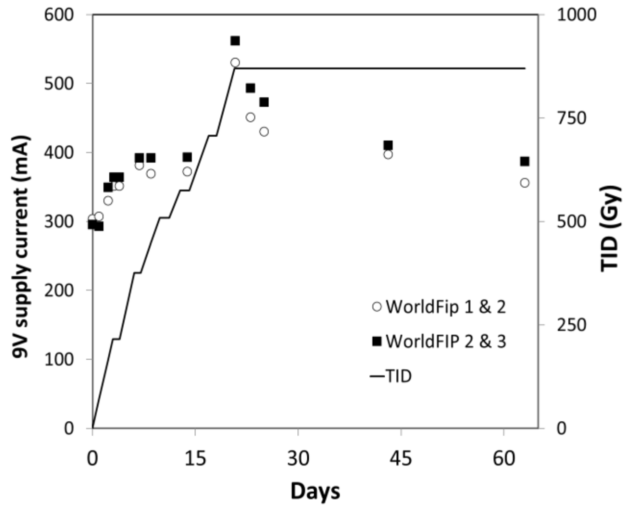
- **Testing cards with new reprogrammable FPGA**
  Approximately 1 automatic action (local or remote) every ~1000 Gy (tunnel).

- **Observation on the ADC**
  A new delivery of a long used component (ADC) was found sensitive.
  → Existing productions are OK.
  → To pay attention at future productions.

Paper on Smartfusion2 FPGA under publication: ***https://edms.cern.ch/document/2050890***

FIP card internal errors – Power consumption

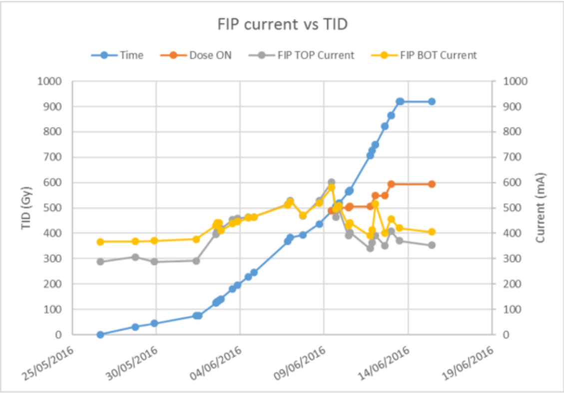
2014/2015	
WFIP1&2	MMW000208
WFIP3&4	MMW001255
2016	
TOP	MMW000371
BOT	MMW000102
2017	
TOP	MMW001255
BOT	MMW000208
TOP	MMW000371



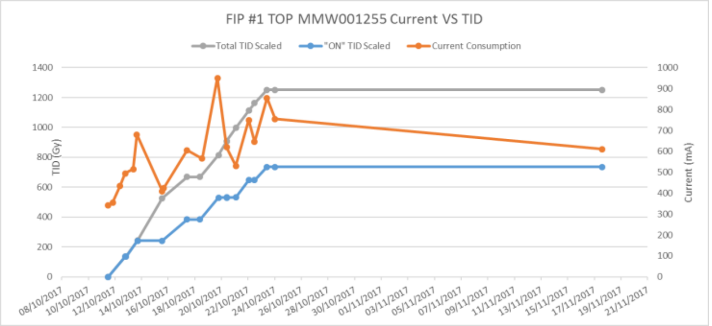
2014/2015

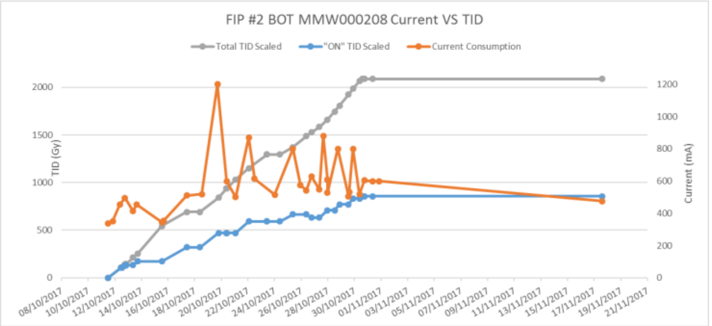
All 3 irradiation combined TID (Gy)

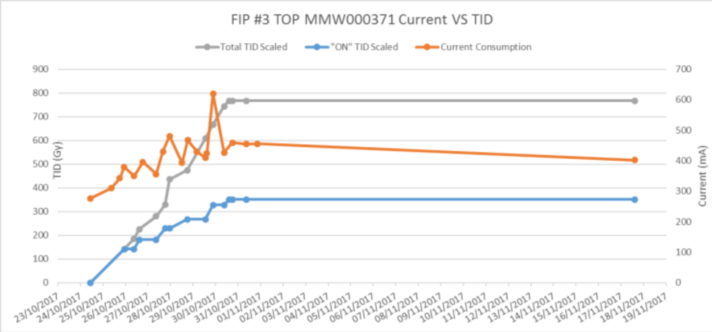
FIPs	TID Total	TID "On"
MMW000208	2958.9	1801.6
MMW001255	2121.6	1604.4
MMW000371	1686.8	1166.9



2016





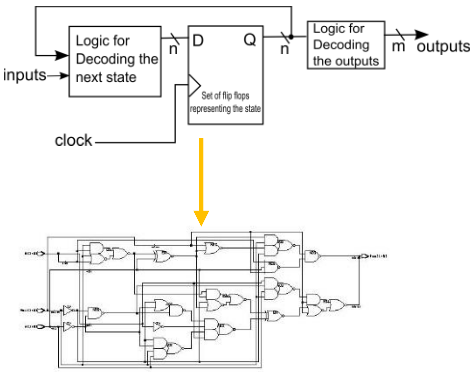


2017

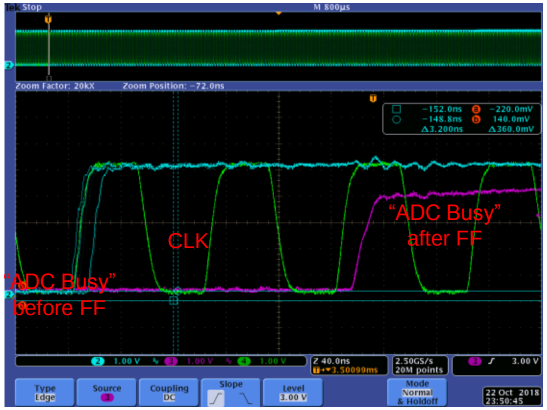
2017: Used cards of previous CHARM tests.
Very high annealing when powered off. All cards are still functional.

Example of ongoing unforeseen consolidation.
Metastability problem on the antifuse TT FPGAs. For 2019.

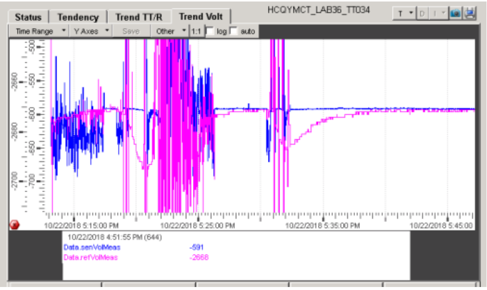
- “Random” erratic behavior seen on some type of cards → Problem understood: FPGA metastability on asynchronous inputs.
- So far problem was treated by replacing the FPGA to another “newer” code version that does not suffer from this problem.
- FPGA cannot be reprogrammed → Addition of a flip-flop component patch (FF).



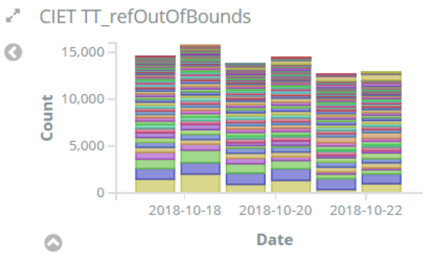
Timing violations lead to wrong state in the FPGA statemachine → Reset



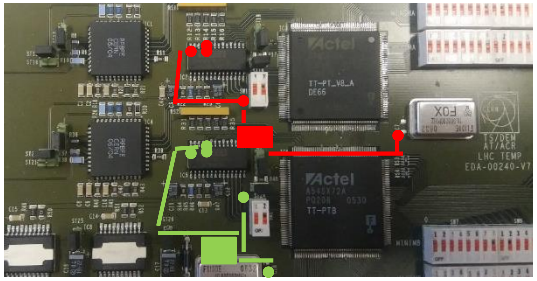
Problem solved after synchronizing the busy signal



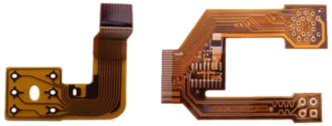
Tested at 2 spiky cards removed from the tunnel. Noisy when original card; no noise with extra FF.



Currently 115 channels + 80 masked out of ~1100 channels



Location on the TT card for flex PCB patch

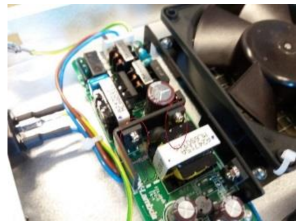


Example of flex PCB solution
Estimated cost: < 10 CHF

Radiation test specs ready.
To test around Jan/Feb 19.
Test deployment during LS2.

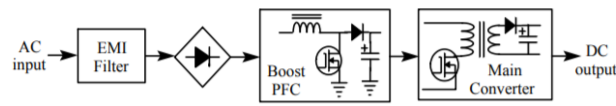
AC/DC 24V 50W device TDK-Lambda ZWS50BAF24

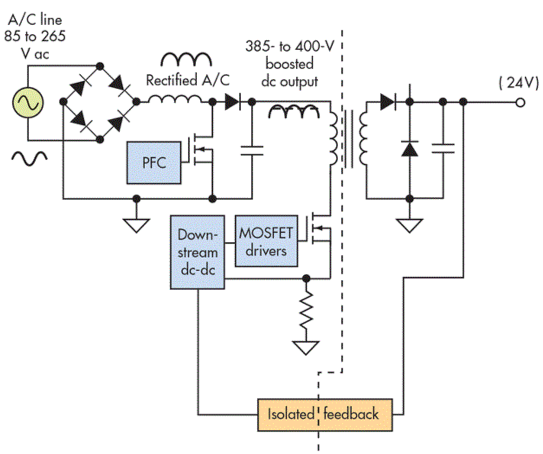
- **Non critical low count ventilator devices installation in shielded areas.**
- **After some failures in LHC, mosfets replaced to rad-tol FCA36N60NF.**
- **After more failures on the modified supplies, the circuit was analysed.**



Original power mosfets

Modified power mosfets



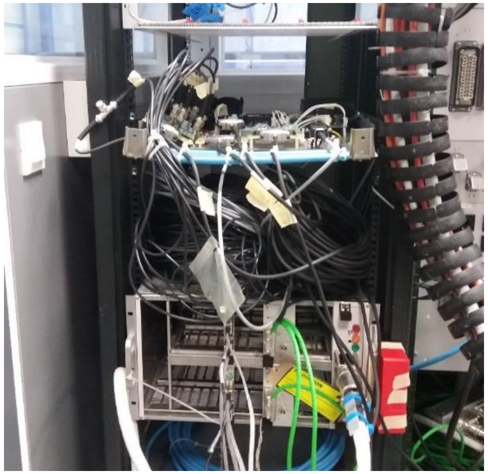


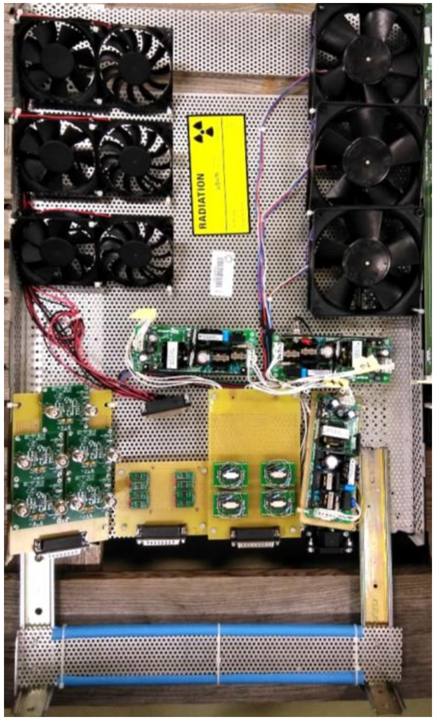
Original circuit produces 400 VDC and power mosfets see 475-500 VDC!
After disabling the power factor correction circuit, DC voltage at 325 VDC
And power mosfets see 400 VDC.

Tested units:	**Failed at:**
#1 Rad-tol Mosfet +47V zener without /PFC	#1 300 Gy, 1.19 10^{12} HEH
#2 Rad-tol Mosfet without zener/PFC	#2 289 Gy, 1.14 10^{12} HEH
#3 Rad-tol Mosfet without zener/PFC	#3 568 Gy, 2.25 10^{12} HEH
#4 Original mosfets without zener/PFC	#4 **4 Gy, 1.58 10^{10} HEH**

But finally we will install custom rad-tol linear regulator from crate supply (27 - 33) V to 24 V.

Misc devices/components e.g. 2017





FANs:
Ebmpapst VarioPro 4314/17T (4.8W @ 24V)
Microblow FMA8012BS-M (1.44W @ 12V)
SUNON PF80201V1-000U-A99 (3.42W @ 12V)

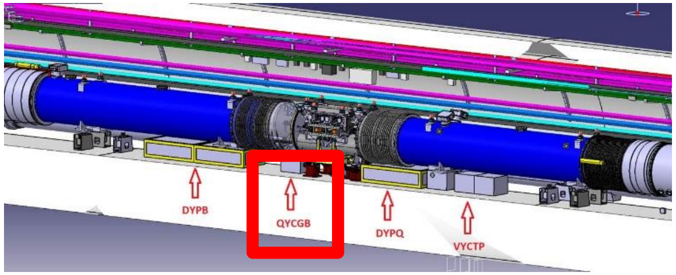
OPAs:
OPA132
OPA137
OPA192
OPA129
OPA602 (selected lower cost precision OPA replacement for the OPA627)

***AC/DC** 24 V 50W Unit (TDK-Lambda ZWS50BAF24)*

Rad-Tol: Electronics Strategy

<u>Strategy to cope with failures and radiation effects:</u>

- Track power consumption for individual cards/crates to assess TID effects.
  Presently done in R1 on 10 crates (72 cards) exposed to low and high TIDs.
- On “high” radiation areas leave RadTol crates (<10 over 800) to assess:
  - Radiation effects (if any); maximum TID (if ever reached).
  - Foresee local cable to relocate equipment
    to middle of cold mass for R7/L7 11T case.



- Keep adequate quantity of spare cards and components.
- Cards rotation could be option as most cards installed in the ARCs (low TIDs).

<u>Regular maintenance/monitoring is a routine task:</u>

- Requests for intervention and corrective actions stored in logbooks.
- Long-term signals and diagnostic data in logging database.
- Daily automated database queries on a set of pre-defined rules to detect potential problems (Elasticsearch/Kibana).

Rad-tol electronics perform as expected.
(However other lifetime reliability problems might occur earlier).

Summary

- Most of the CRG equipment shall perform satisfactorily under HiLumi conditions:
  - Radiation tests are performed once/twice per year. Essential to cope with obsolescence and to qualify new devices.
  - CRG dedicates already about 0.5 FTE for radiation issues.

- Material/devices purchased/scrapped for/after tests: **10 to 30 kCHF/year.**
- HiLumi: Stay as is; provisionally install cables to relocate cryo-crates for “risk” areas.
- Monitoring/diagnostics/maintenance are continuously being applied to all the equipment that is installed in radiation or radiation-free areas.

- End of life failures: no indication yet for any equipment (electronics, valve actuator, etc).