Status of the LHC power converter* controls

* A CERN “power converter” = everyone else’s “power supply”

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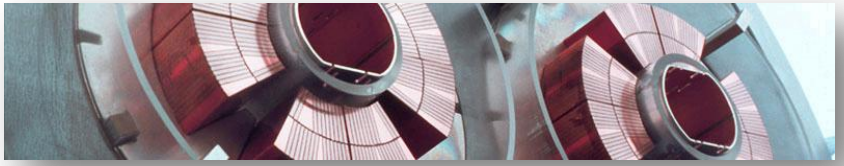
Converter Controls
Electrical Power Converter Group
CERN

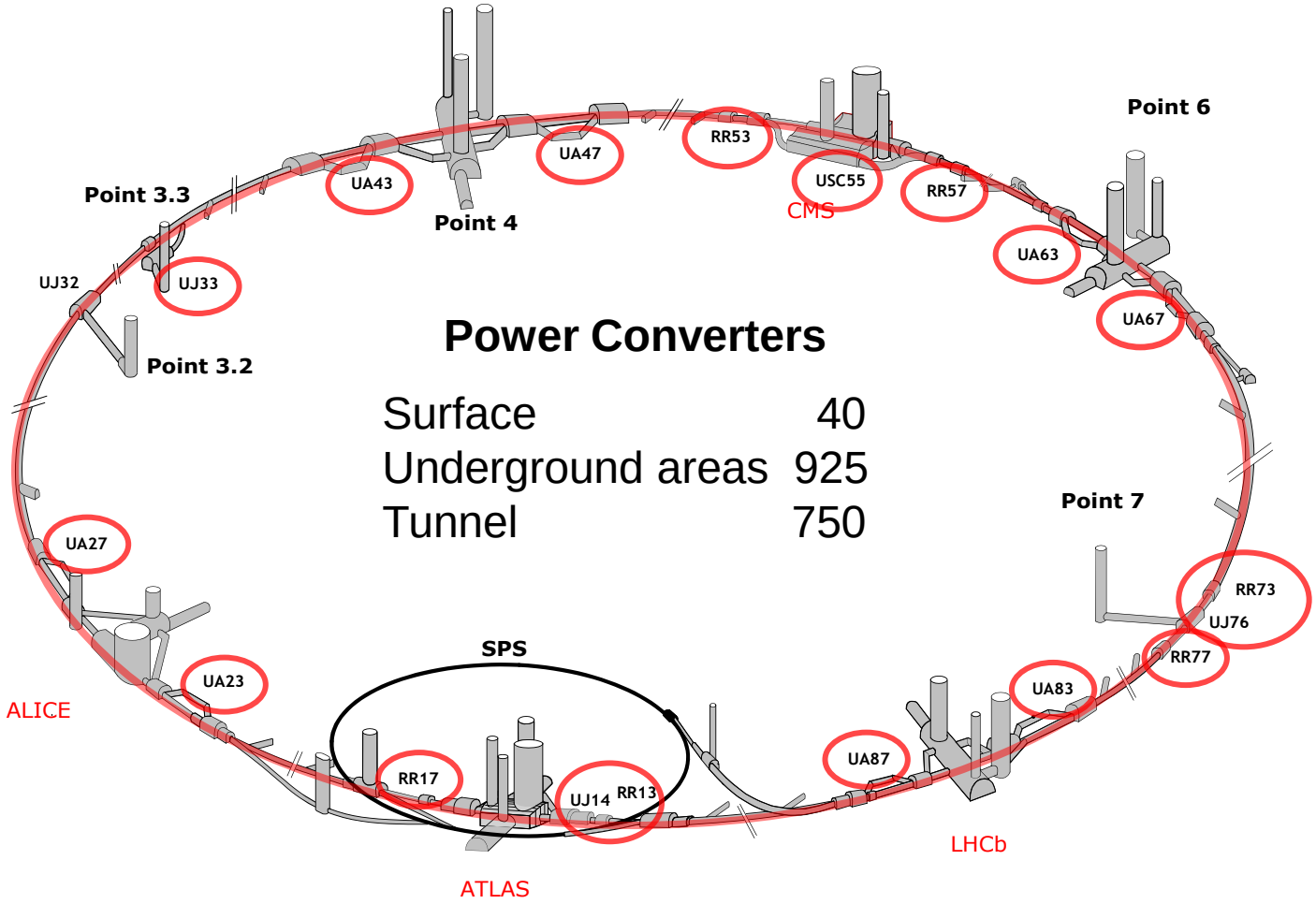
Context



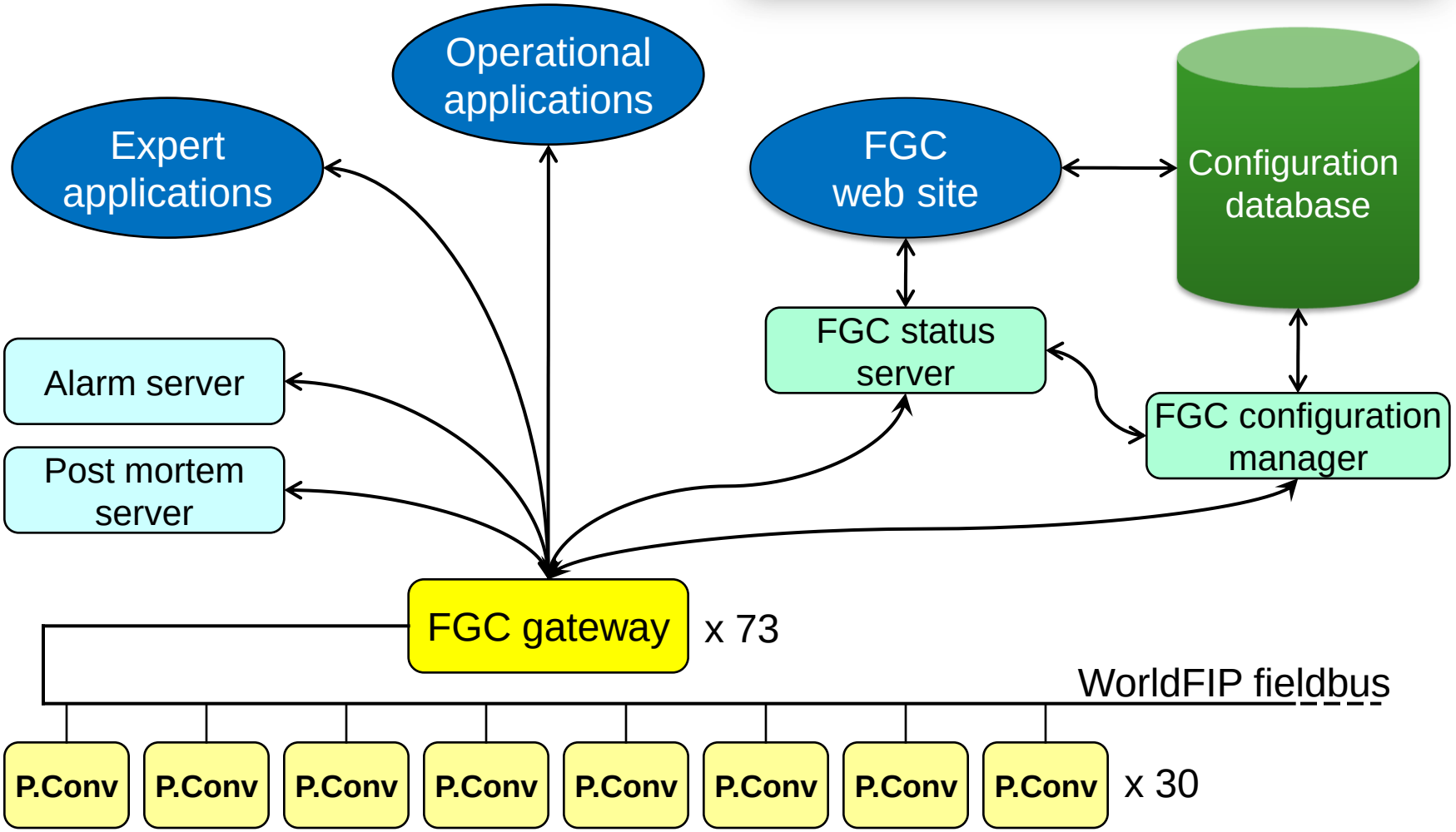
- The LHC has ~1700 magnet circuits, each driven by a power converter
- Each power converter is controlled by an embedded computer called a Function Generator/Controller (FGC)

- The complete powering system cost 86 MSF + 280 FTE years
- The controls cost 7 MSF + 50 FTE years (8% + 17%)
- 2000 FGCs have been produced and 1700 have been installed in the LHC since 2007
- The LHC experiments also use FGCs to control their magnet power converters

LHC powering

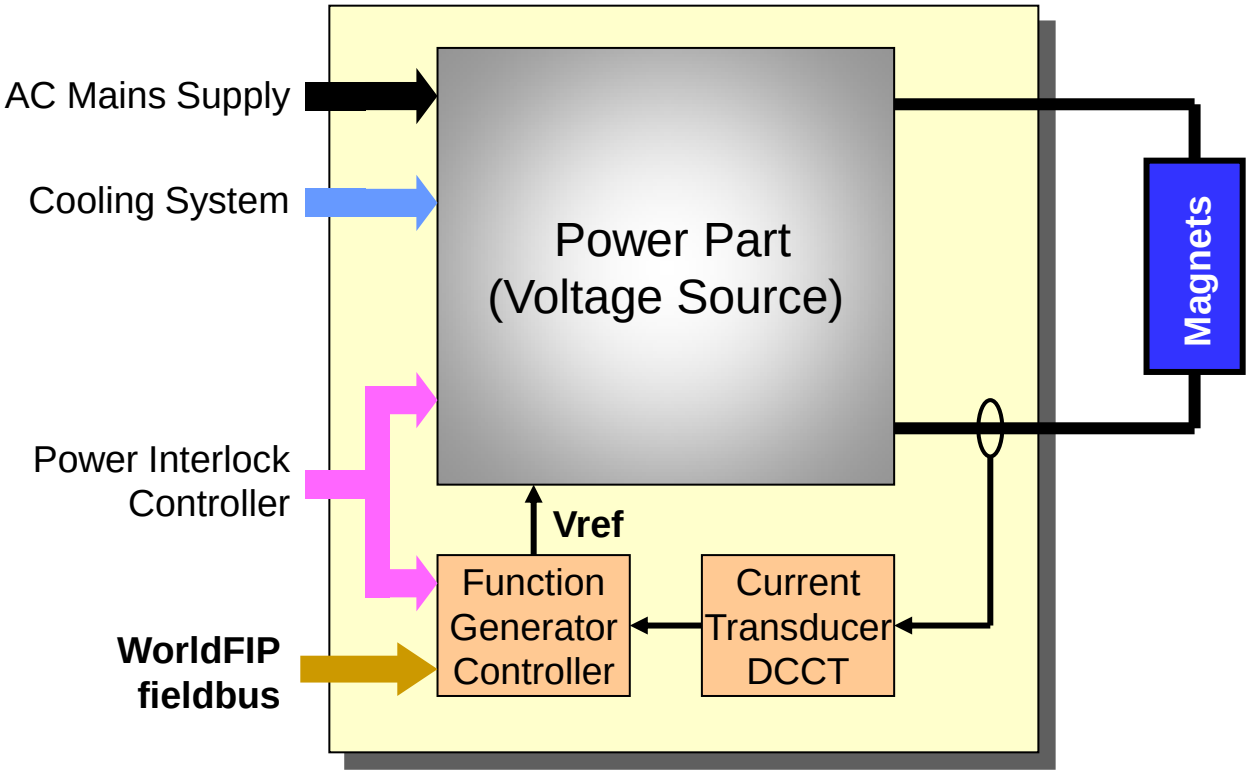


System Architecture



Power Converter

- LHC power converters are current sources
- They are made from a voltage source, current transducer and a Function Generator/Controller (FGC) running a digital current regulation loop



- Application defines:

  Current vs. Time

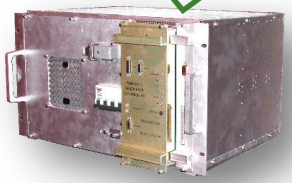
FGC

- Embedded computer designed specifically for LHC power converters
- Microcontroller + Floating point DSP
- Error corrected memory
- 2 ADC channels to measure the current
- 1 DAC to send the voltage reference to the voltage source
- Digital inputs and outputs to control and monitor the voltage source
- Metal cassette to protect the circuit boards

Power Converter Types

±60A ±08V`480W

730 Units



±120A ±10V 1.2kW

300 Units

±600A ±10V 6kW

400 Units

±600A ±40V 24kW

40 Units

Power Converter Types

4/6/8kA 8V 32/48/64kW

200 Units

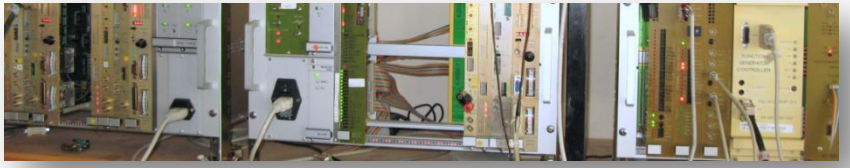
13kA 18V 234kW

16 Units

13kA ±190V 2.47MW

8 Units

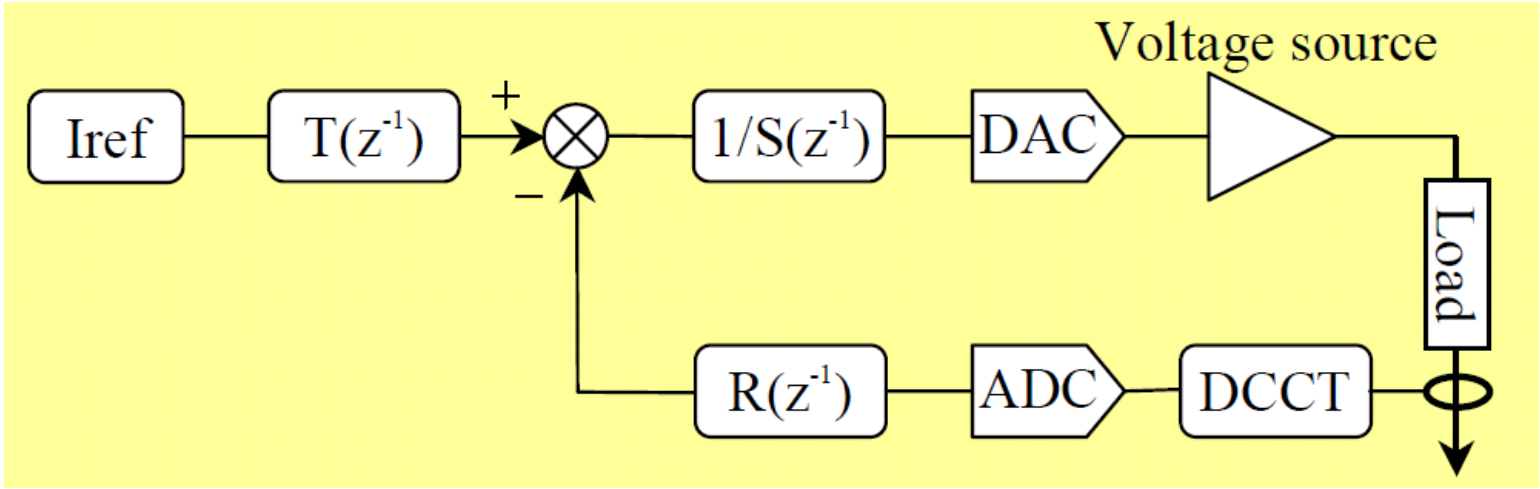
WorldFIP



- Presented at ICALEPCS 2005
- 2.5 Mbps real-time fieldbus
- Supports:
  - Time and events distribution
  - Commands and responses
  - Real-time publication of status
  - Real-time control of current
  - Software updates
  - Remote Terminal access

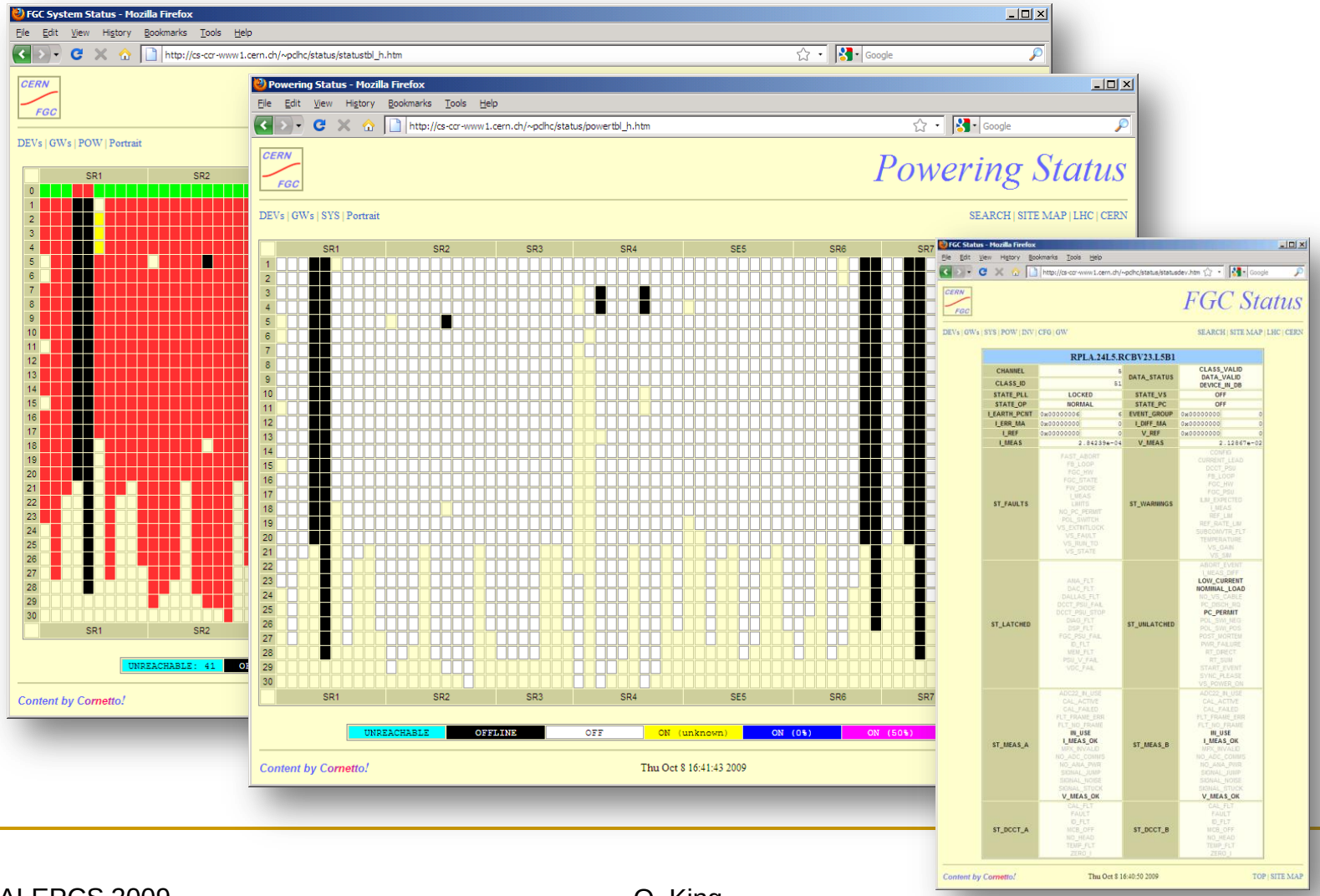
- Low throughput per FGC but WorldFIP supports parallel communications, so an application can send commands to all 1700 FGCs simultaneously (120ms for most commands)
- CERN now owns the Alstom WorldFIP intellectual property

Current Regulation

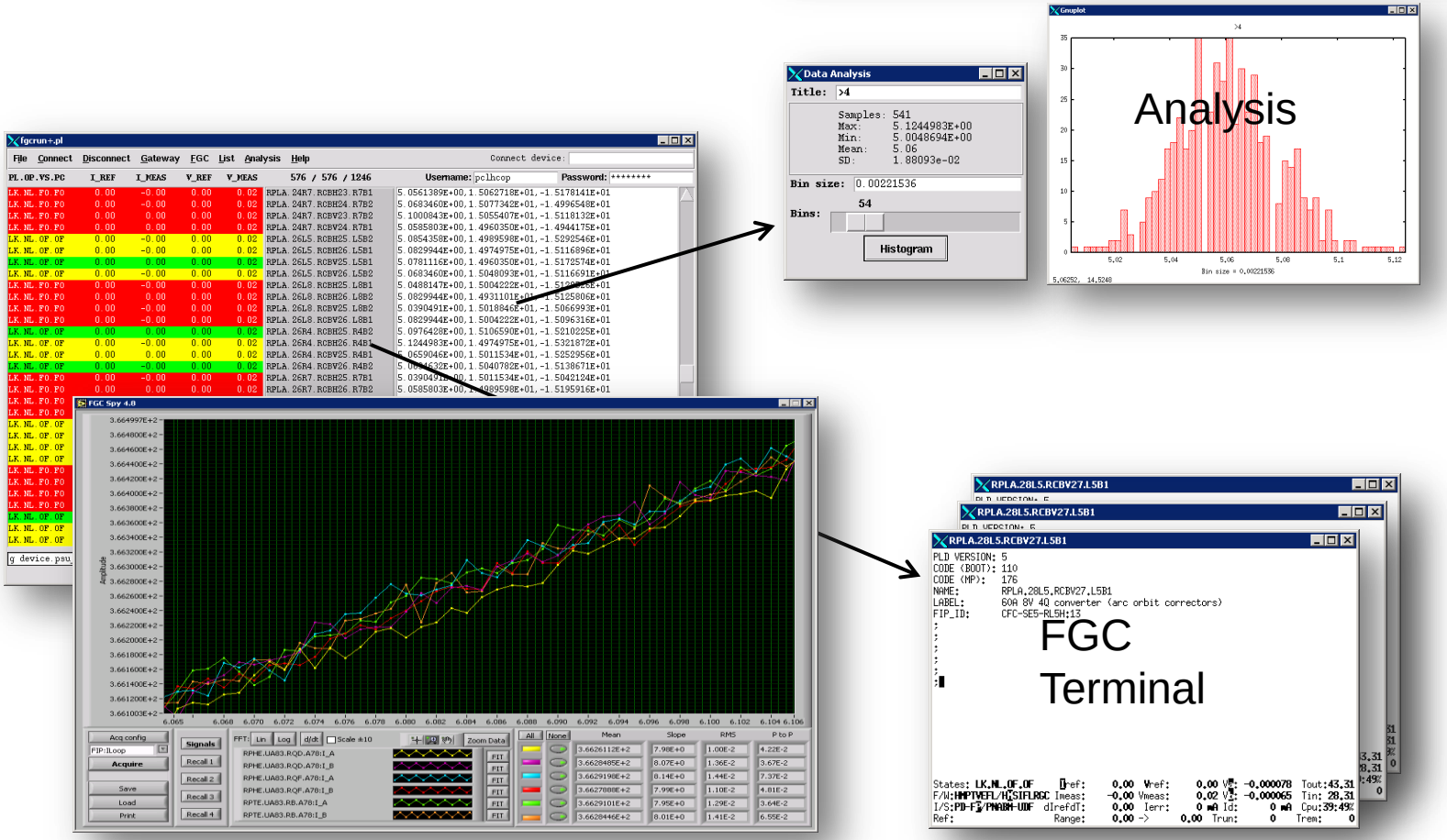


- Digital Regulation uses a proportional-integral-integral controller (PII)
- Implementation uses an RST tri-polynomial algorithm
- Excellent results – no overshoot and no tracking errors during the ramps

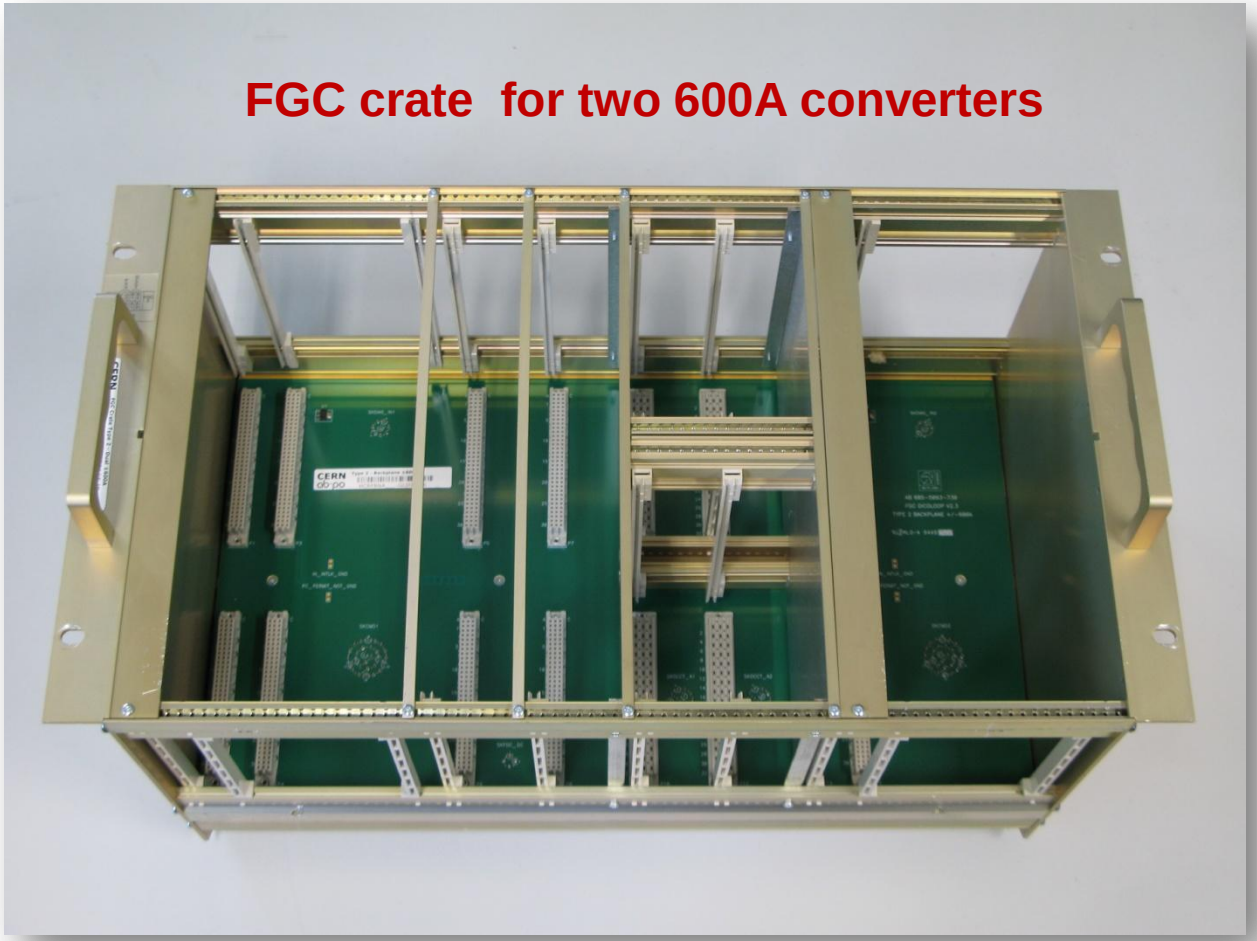
Status web pages



Expert tools



FGC Crate

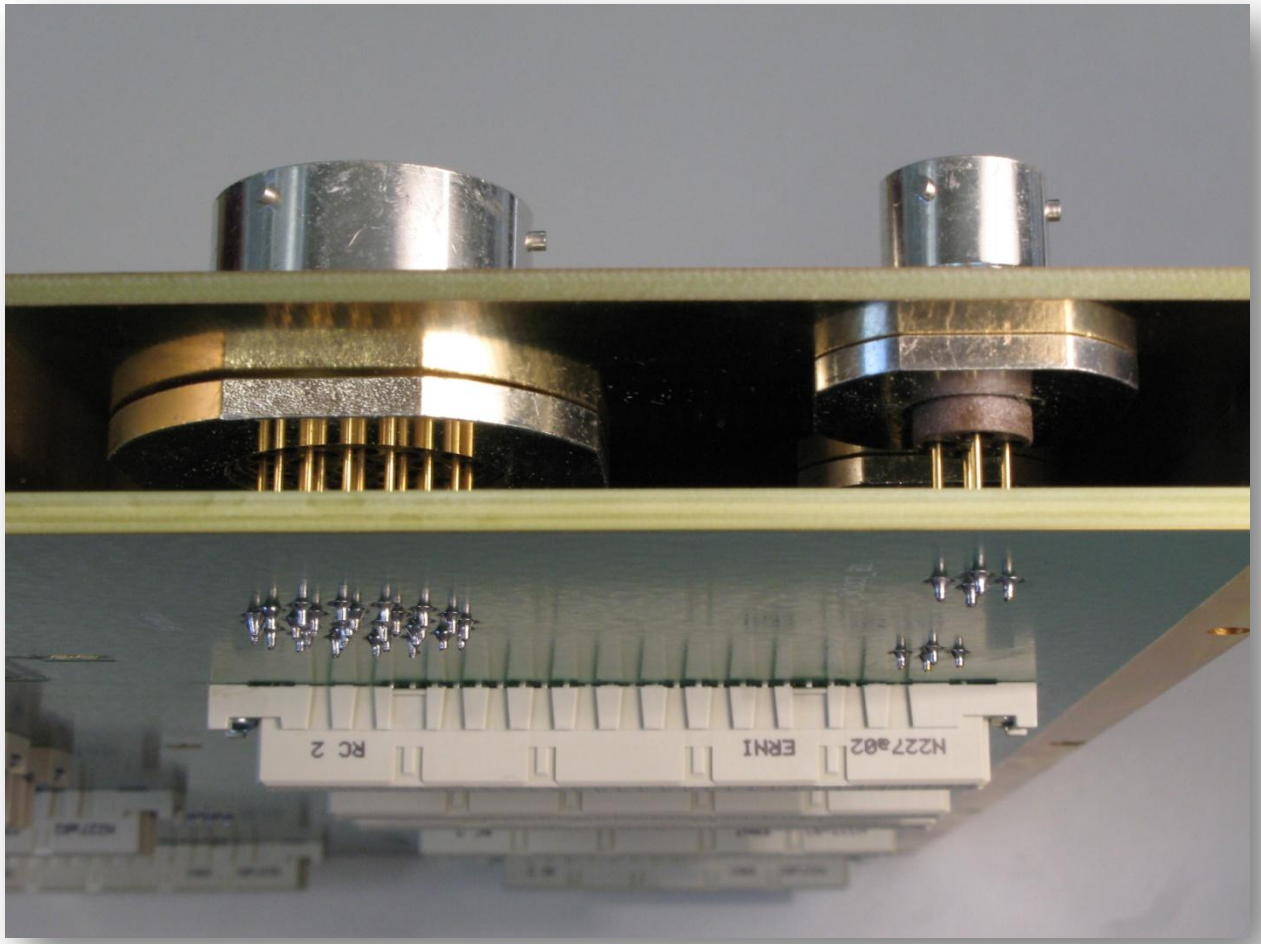


FGC Crate


HCRFMCA___-JT000176


SKDIAG IN2
SKDCCT B2
SKDCCT B1
SKDIAG IN1
FGC CRATE – TYPE 2
HCRFMGA
AB 685-5093-032
SKCMD2
SKCMD1
SKDCCT A2
SKDCCT A1
SKFGC DC

FGC Crate

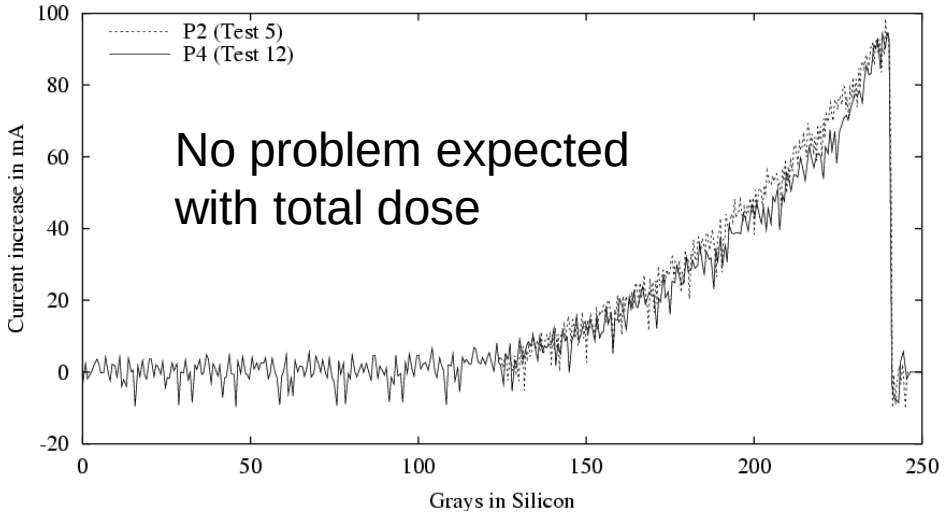


Radiation

- 750 converters are in the tunnel with ~10^{10} particles/cm^2/year (E>20MeV) expected for nominal LHC operation
- Another 200 converters are in underground areas that will have lower but still significant radiation levels
- The FGCs were designed to tolerate this level and were tested at a 60 MeV cyclotron

- Single event upsets were seen
- Error corrected memory
- Use flash based CPLDs rather than RAM based FPGAs

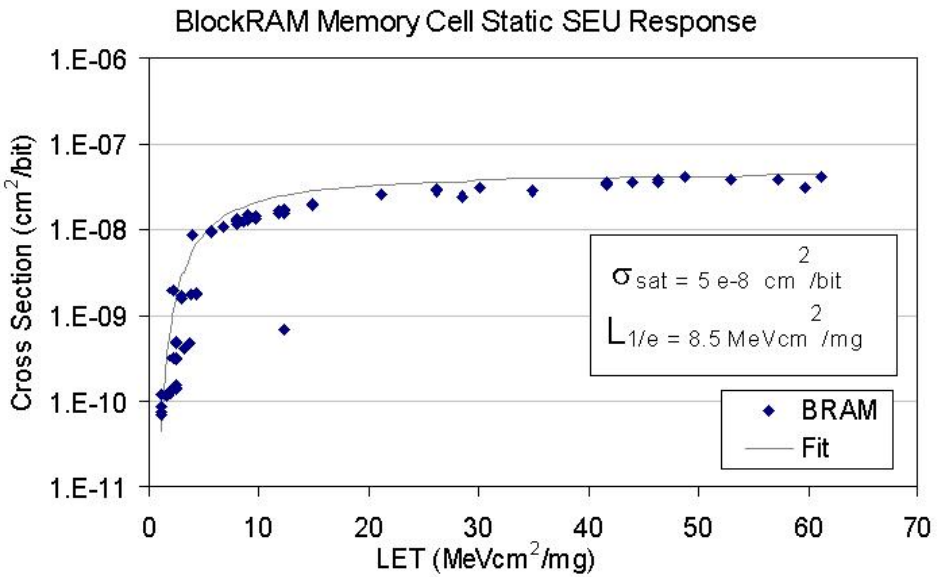
Figure 9: CPU CPLDs current increase against dose



Single Event Latch-ups

- Latch-ups require a power cycle to clear and none were seen because 60 MeV protons were not sufficiently energetic – we should have used a 250 MeV beam instead
- Tests using the CERN SPS accelerator have now shown that the Xilinx 95 series CPLDs ***do*** latch-up and even burn out

- Converters in the tunnel are redundant so a power cycle won't lose the beam
- Converters in the underground areas are not redundant so latch-ups ***will*** lose the beam
- Tests are on-going and all options are being considered



Summary

- ☺ Metal cassette for the FGC
- ☺ Wiring free backplane
- ☺ WorldFIP Fieldbus
- ☺ XML definition files with a Perl parser
- ☺ AJAX based status web pages
- ☺ Perl-Tk expert interface
- 💣 Radiation tolerance

Conclusions

- The LHC power converter controls are working very well – but the radiation tolerance of the FGCs is still being studied and may be a problem for a small number of converters

- Overall it is a huge system and the effort spent on automatic configuration and diagnostics was well invested

Thanks to:

- My colleagues in TE-EPC-CC
  - Stephen Page, Philippe Fraboulet, Philippe Semanaz, Alex Frassier, Gilles Ramseier, Daniel Calcoen
- The excellent collaboration from my colleagues in TE-EPC, BE-CO and BE-OP
- To you for listening!