Status of the LHC power converter* controls

* A CERN "power converter" = everyone else's "power supply"

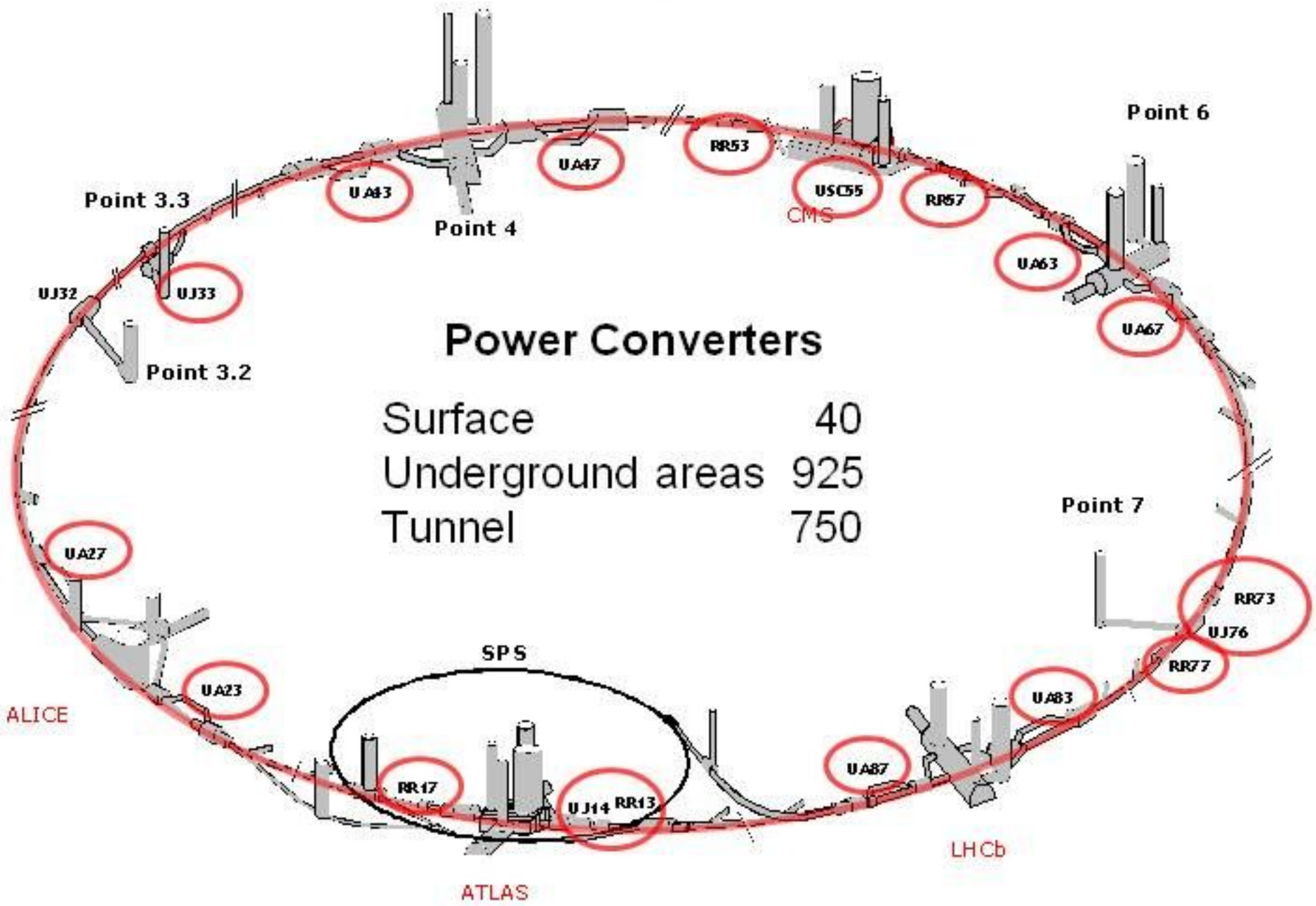
Quentin King
Converter Controls
Electrical Power Converter Group
CERN

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



Power Converters

Surface	40
Underground areas	925
Tunnel	750

System Architecture

Operational applications

Expert applications

FGC web site

Configuration database

FGC status server

Alarm server

FGC configuration manager

Post mortem server

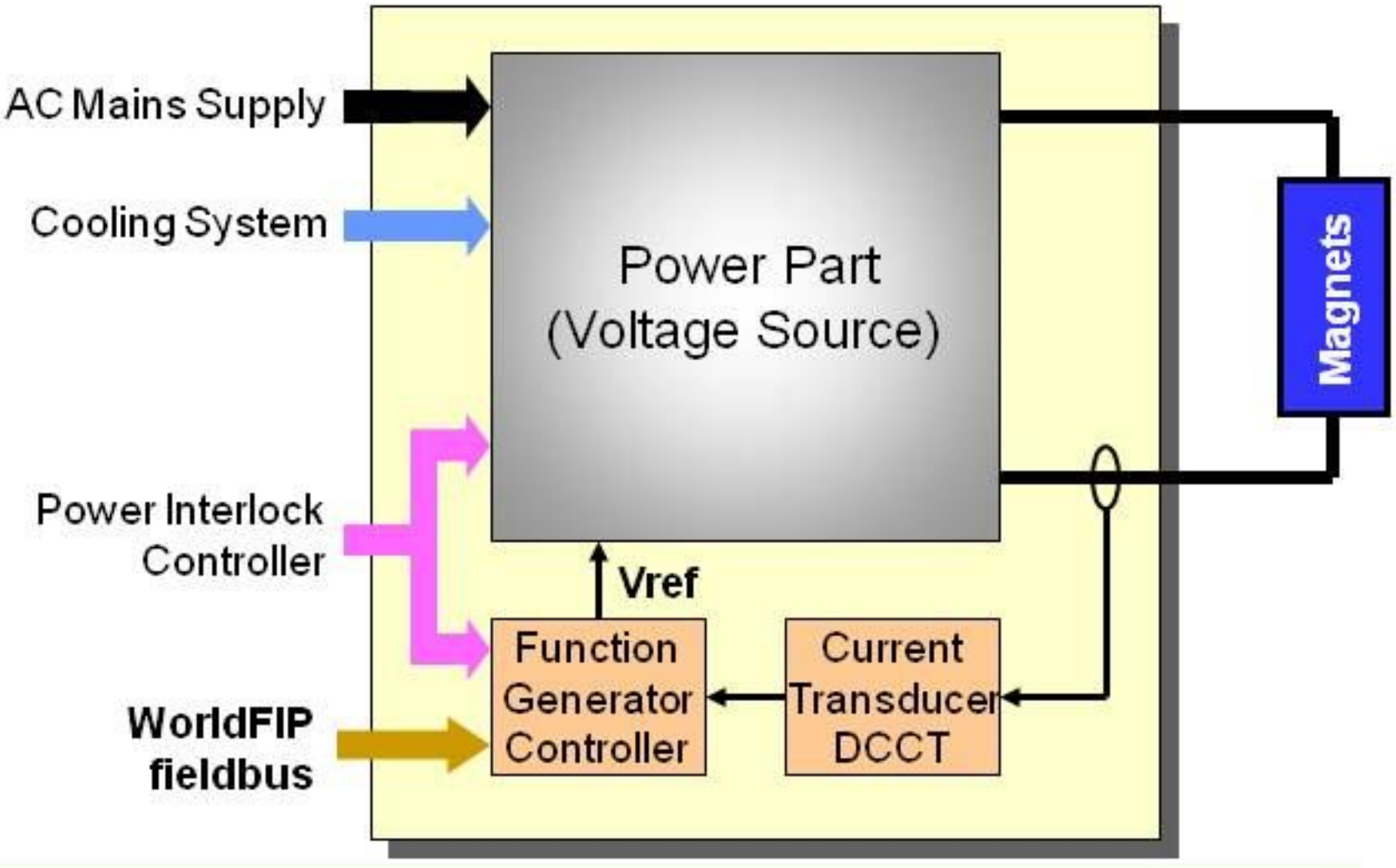
FGC gateway x 73

WorldFIP fieldbus

P.Conv P.Conv P.Conv P.Conv P.Conv P.Conv P.Conv P.Conv x 30

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

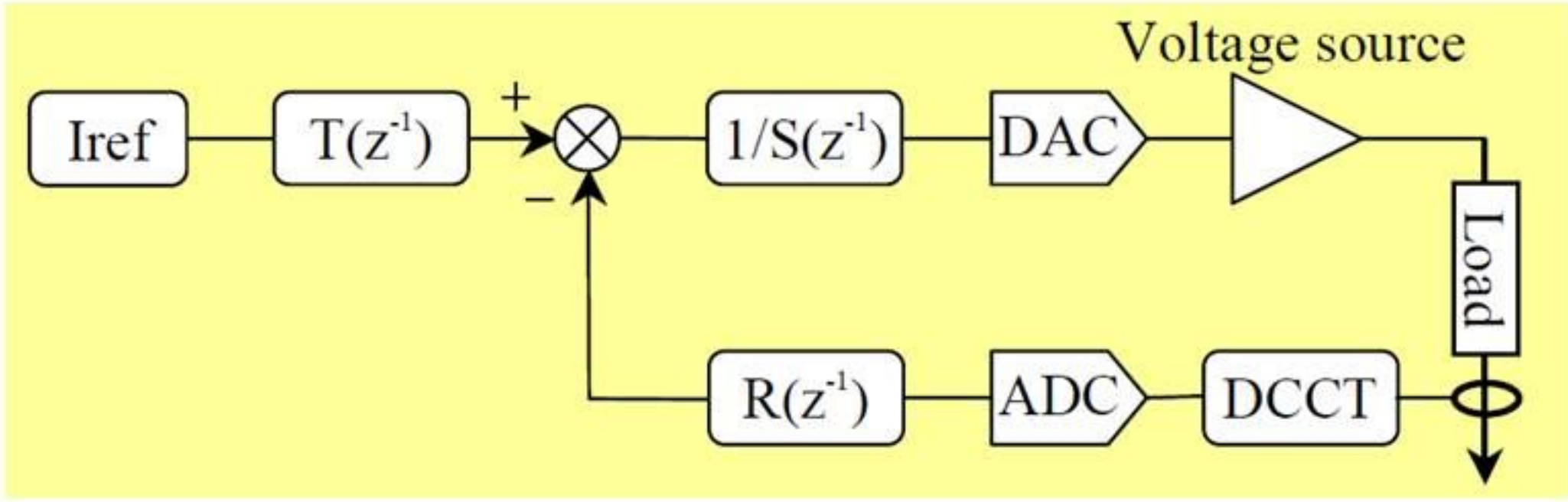
8 Units

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

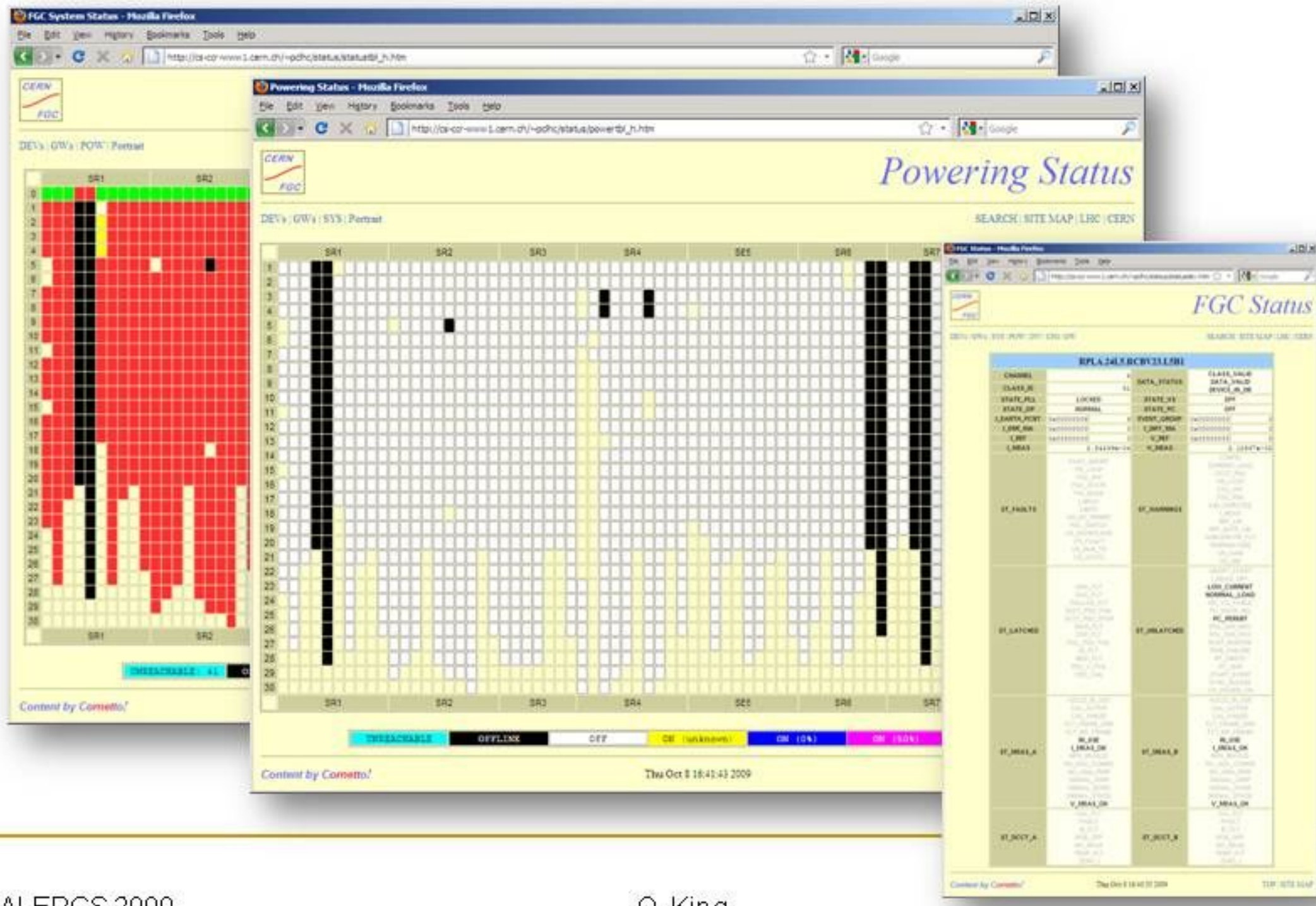
- Low throughput per FGC but WorldFIP supports parallel communications, so an application can send commands to all 1700 FGCs simultaneously (120ms for most commands)
- CERN now owns the Alstom WorldFIP intellectual property

Current Regulation

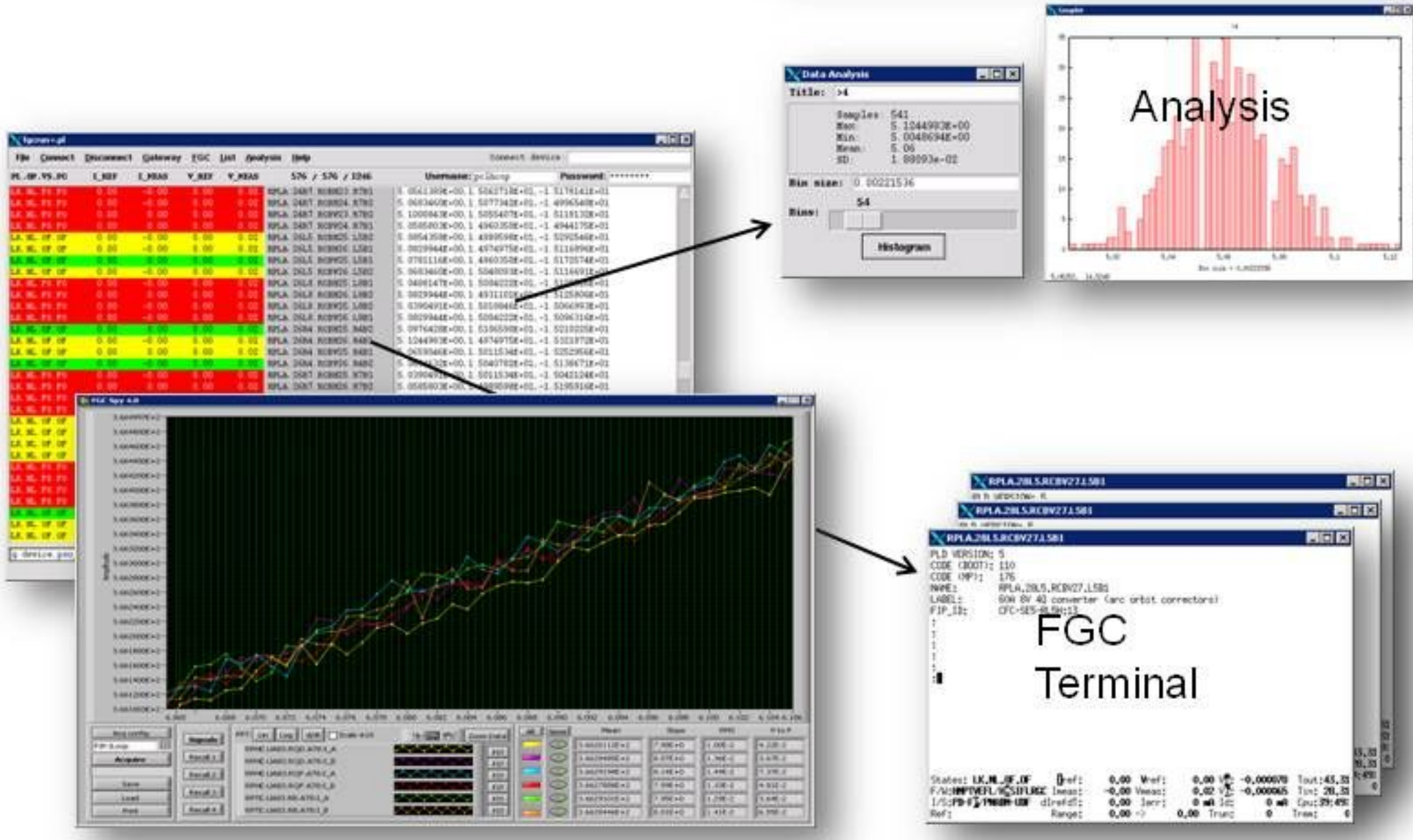


- Digital Regulation uses a proportional-integral-integral controller (PII)
- Implementation uses an RST tri-polynomial algorithm
- Excellent results – no overshoot and no tracking errors during the ramps

Status web pages



Expert tools

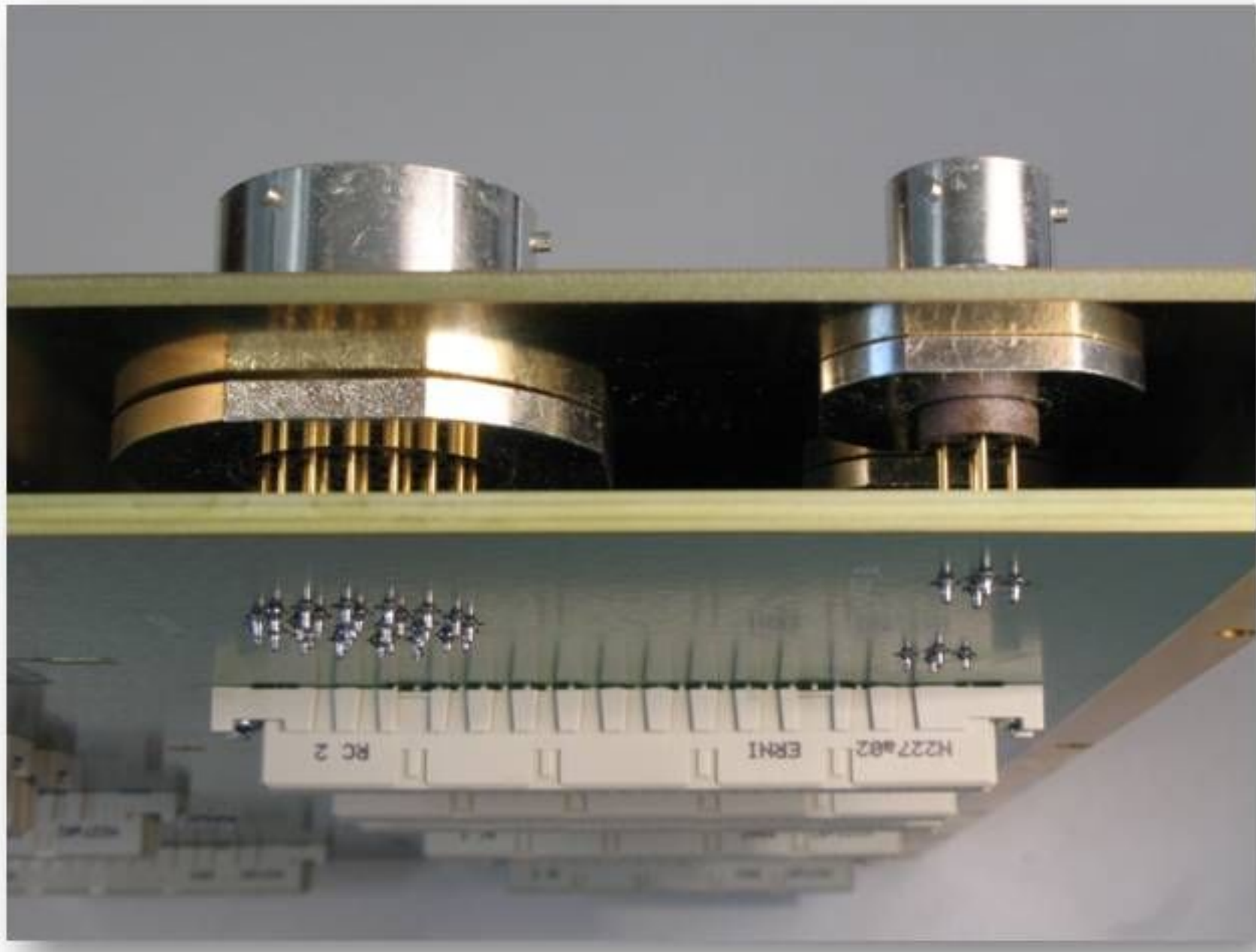


FGC Crate

FGC Crate


HCRFMCA___-JT000176
SKDIAG IN2
SKDCCT B2
SKDCCT B1
SKDIAG IN1
CERN
FGC CRATE – TYPE 2
HCRFMGA
AB 685-5093-032
SKCMD2
SKCMD1
SKDCCT A2
SKDCCT A1
SKFGC DC

FGC Crate

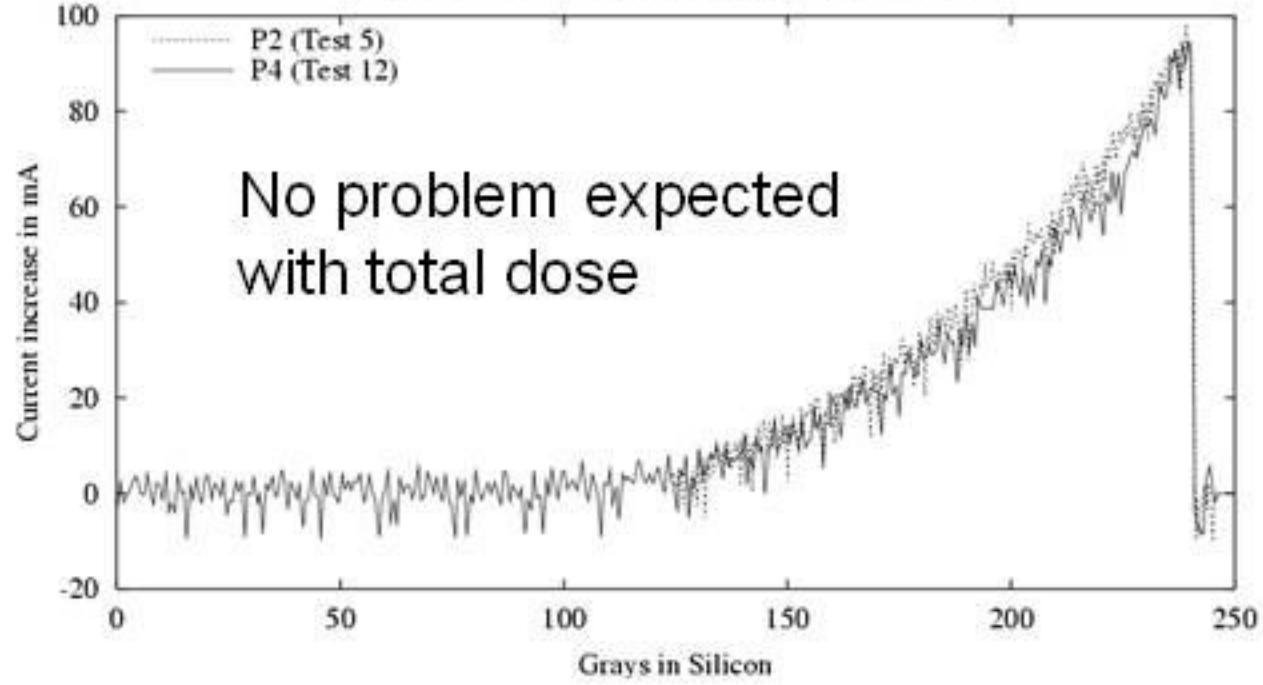


Radiation

- 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

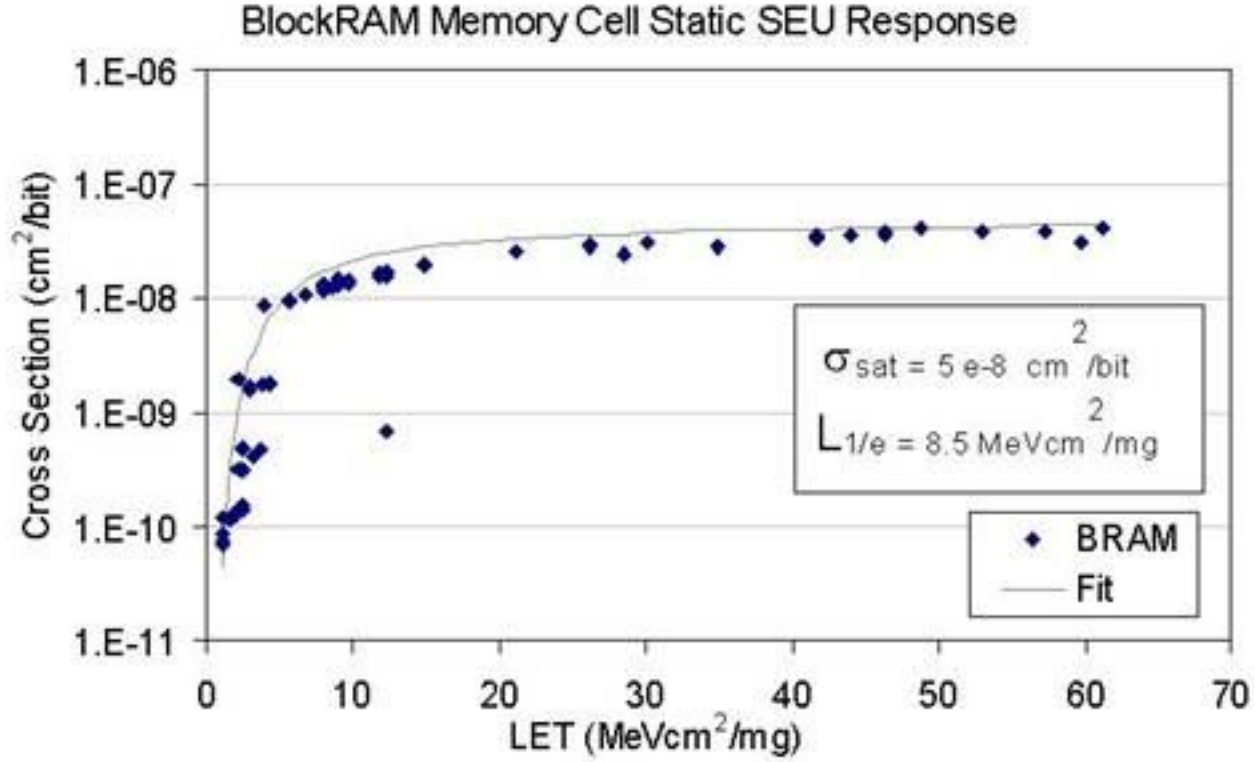
- Single event upsets were seen
- Error corrected memory
- Use flash based CPLDs rather than RAM based FPGAs

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!