Experience with FC7 Failures

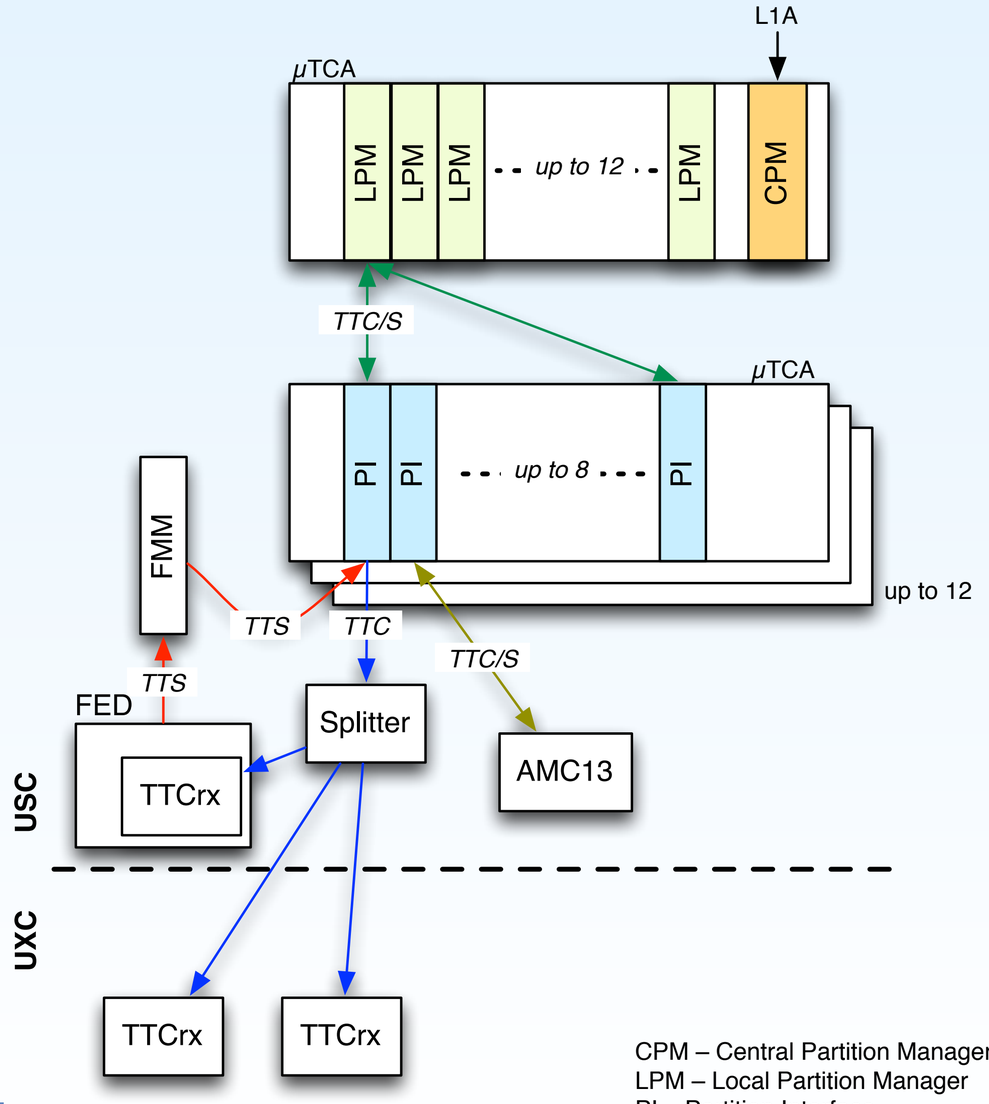
J. Troska

on behalf of the CMS TCDS team

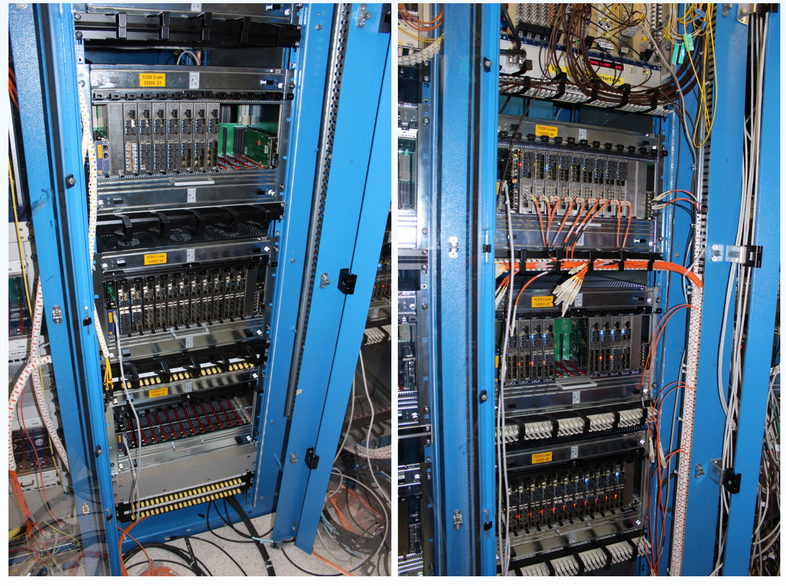
Overview

- Context: CMS TCDS system
- FC7 board overview
- Operational experience & failures
- Failure analysis
- Solution validation
- Summary

Context: CMS TCDS System



- Replaced existing TTC/TCS system during LS1
  - Based on μTCA
  - Increased number of sub-detector partitions
  - Increased flexibility in Trigger Control & Monitoring
- 2 racks, 6 shelves, ~50 AMCs



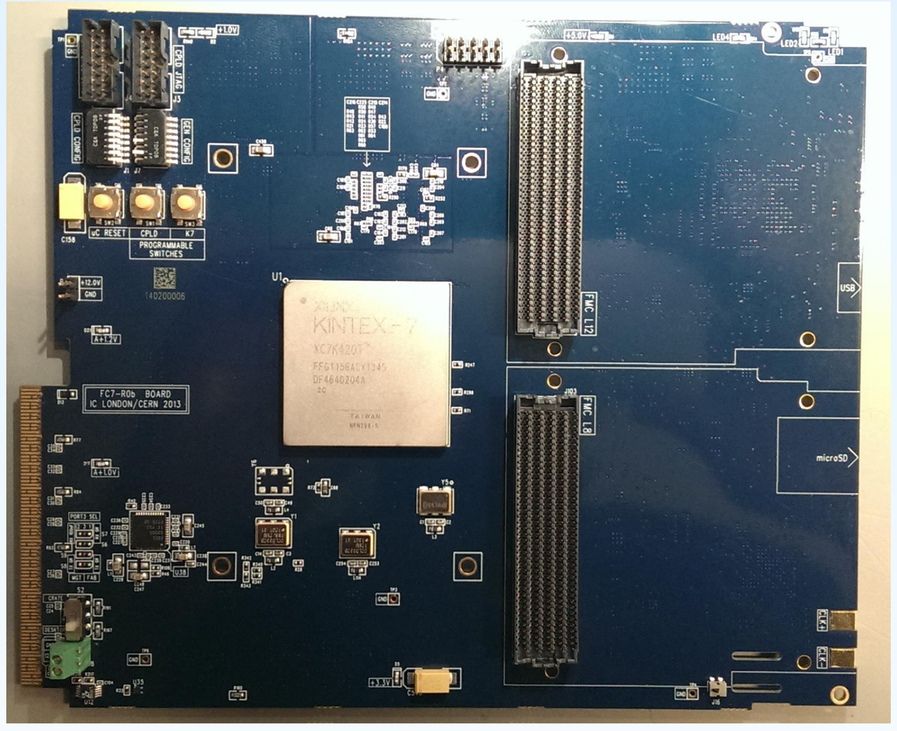
AMC13 – CMS μTCA readout board

FMM – Fast Merging Module

CPM – Central Partition Manager
LPM – Local Partition Manager
PI – Partition Interface

TTC – Timing, Trigger & Control
TTCrx – TTC Receiver ASIC
TTS – Trigger Throttling System

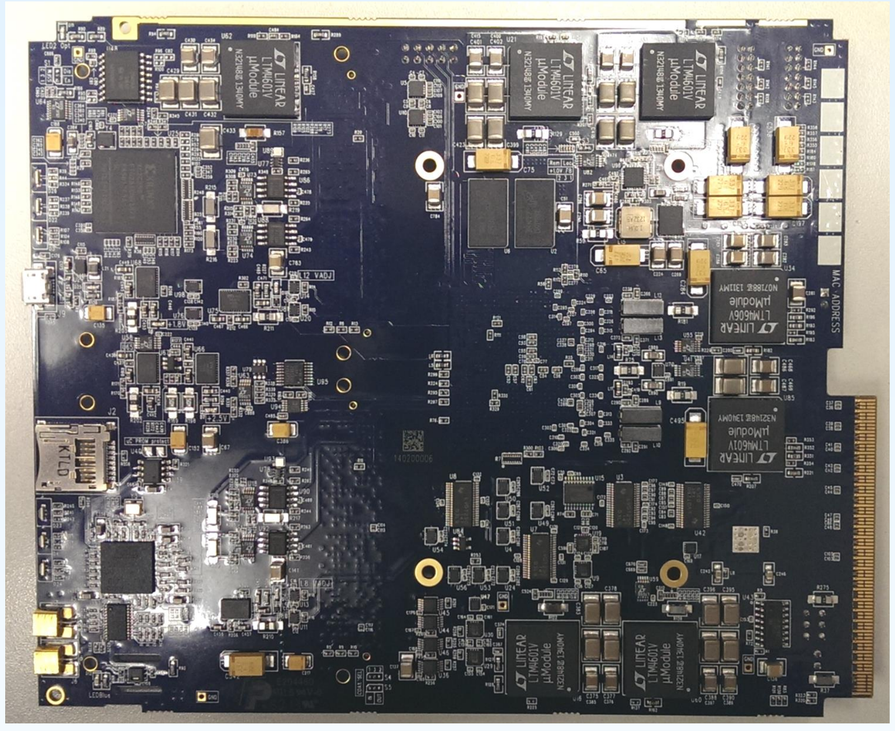
Heart of the system: the FC7 AMC



Joint development by:

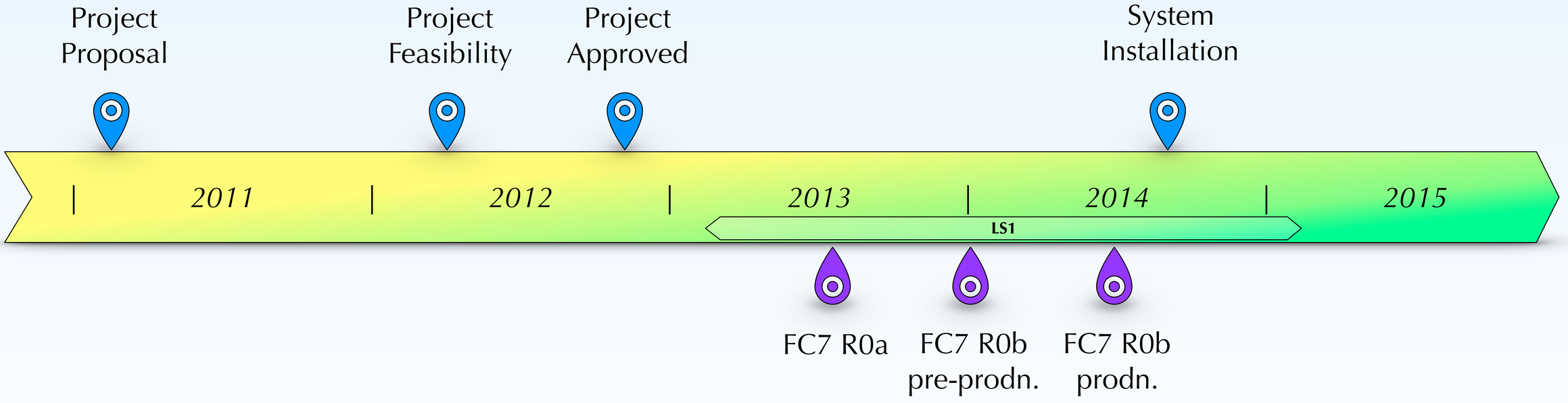
Imperial College London

CERN



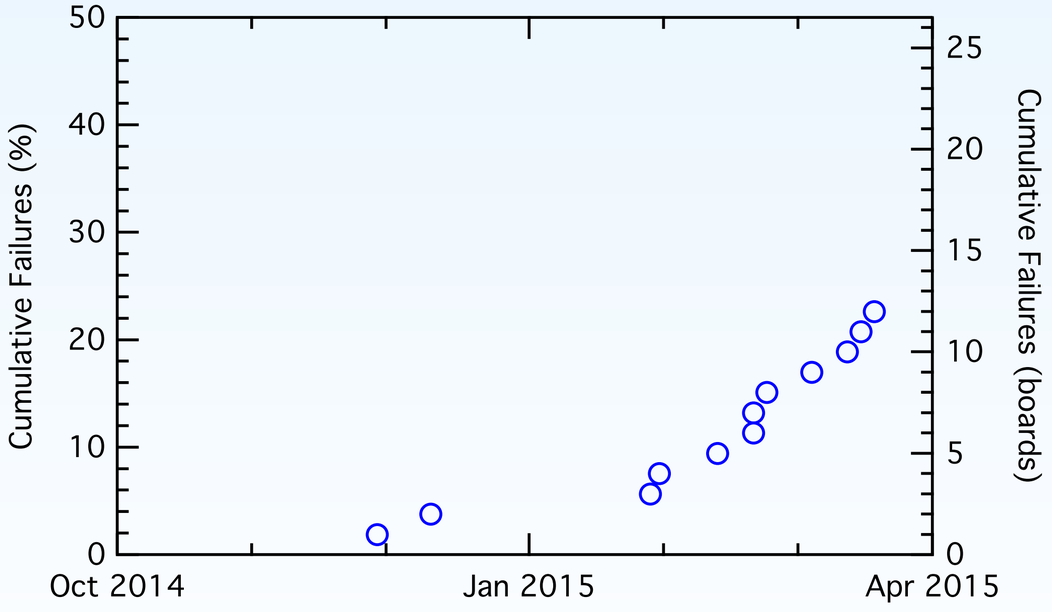
- Xilinx Kintex XC7K420T
  - 10 Gb/s transceivers
- Jitter Cleaner & ref. Xtals
- 2x FMC connectors (LPC+)
- 4Gb DDR3 RAM (128M x 32b)
- Atmel µC MMC & µSD
  - AMC control & FPGA configuration
- 16-layer PCB

Development & Installation Timeline



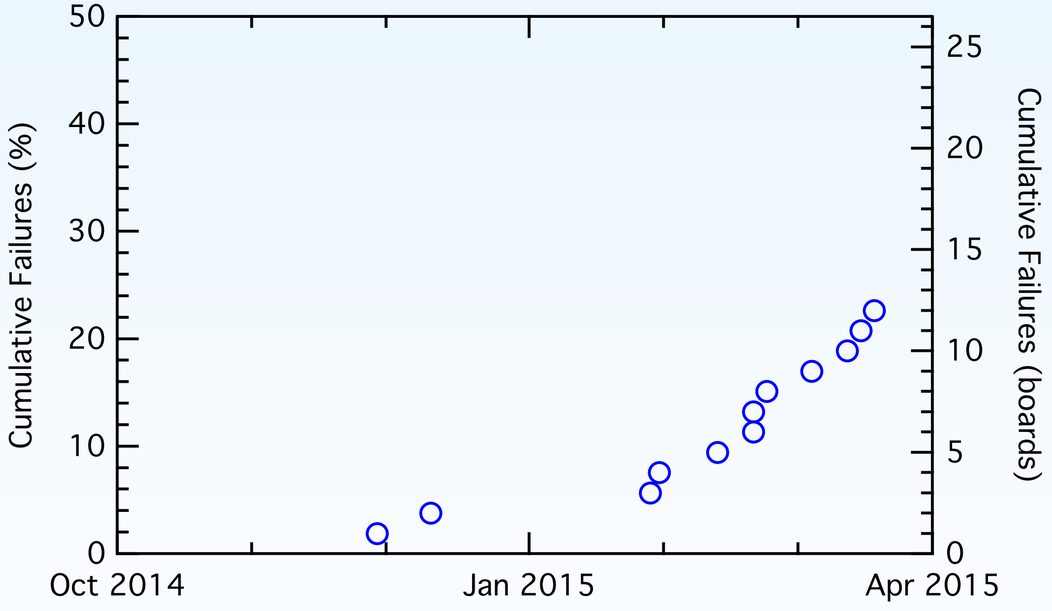
Operational experience & failures

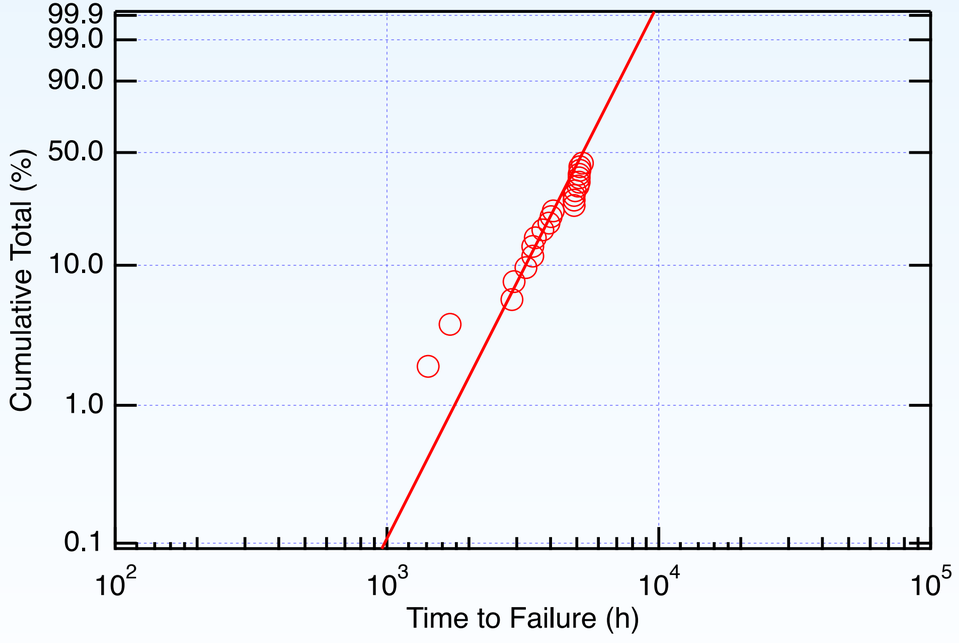
- The CMS TCDS system sustained a very high failure rate of AMCs after ~3 months of operation
  - Full system failure was in sight within ~1 year!



Operational experience & failures

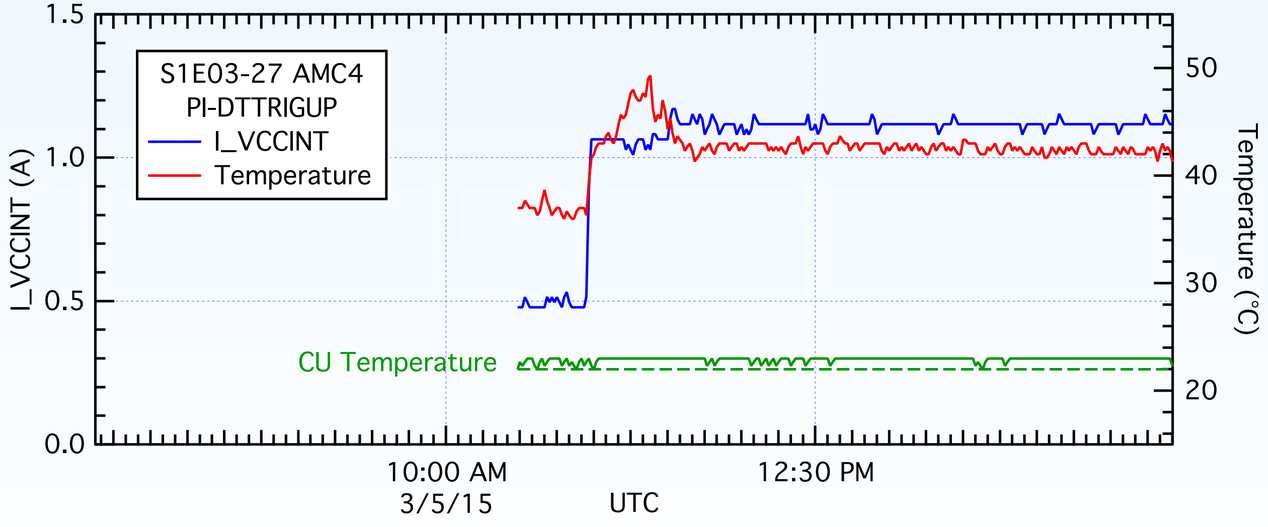
- The CMS TCDS system sustained a very high failure rate of AMCs after ~3 months of operation
  - Full system failure was in sight within ~1 year!





FC7 failure monitoring

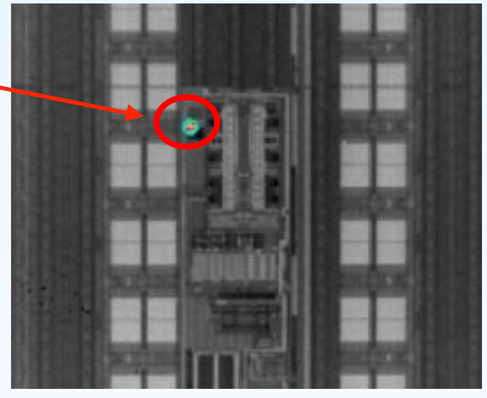
- AMC sensors provided diagnostics
  - Board failure accompanied with increased current drawn on FPGA core voltage
- Increased current an abrupt failure
  - within one monitoring interval (1 minute)



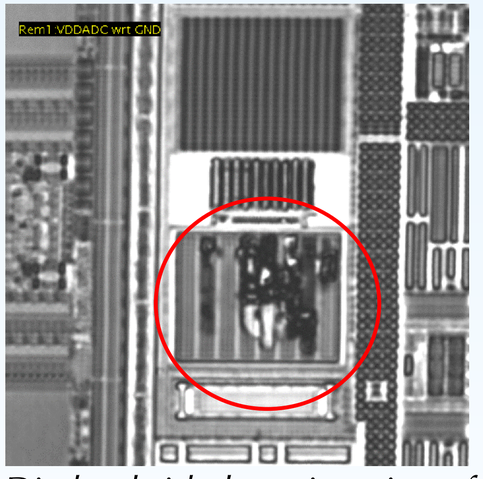
Failure Analysis & Mitigation

- Lengthy investigations & continued monitoring did not reveal problem
- Eventually Xilinx agreed to do Failure Analysis on failed FPGAs
  - Xilinx FA: de-lidding & testing including High-resolution IR imaging for thermal emission analysis
  - Schematic error identified - incorrect XADC supply voltage caused EOS failure of config. memory

Hot-spot



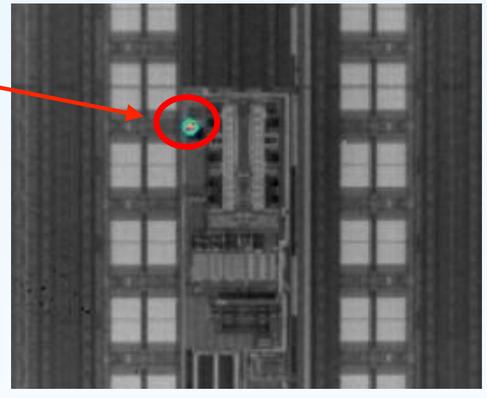
Thermal Emission



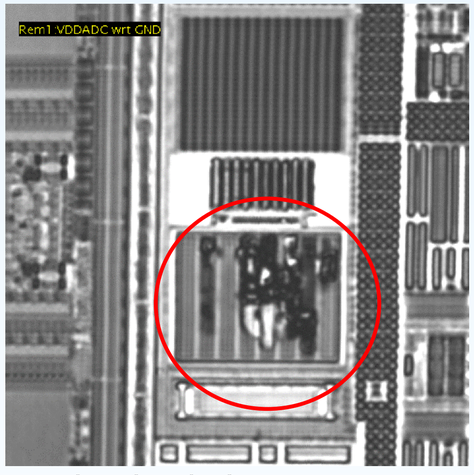
Die backside laser imaging of EOS-induced diffusion damage

Failure Analysis & Mitigation

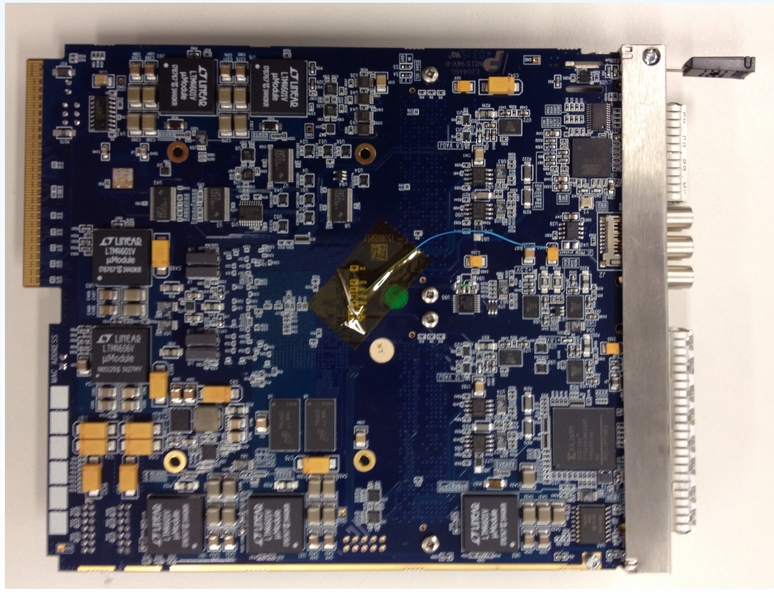
- Lengthy investigations & continued monitoring did not reveal problem
- Eventually Xilinx agreed to do Failure Analysis on failed FPGAs
  - Xilinx FA: de-lidding & testing including High-resolution IR imaging for thermal emission analysis
  - Schematic error identified - incorrect XADC supply voltage caused EOS failure of config. memory



Thermal Emission



Die backside laser imaging of EOS-induced diffusion damage



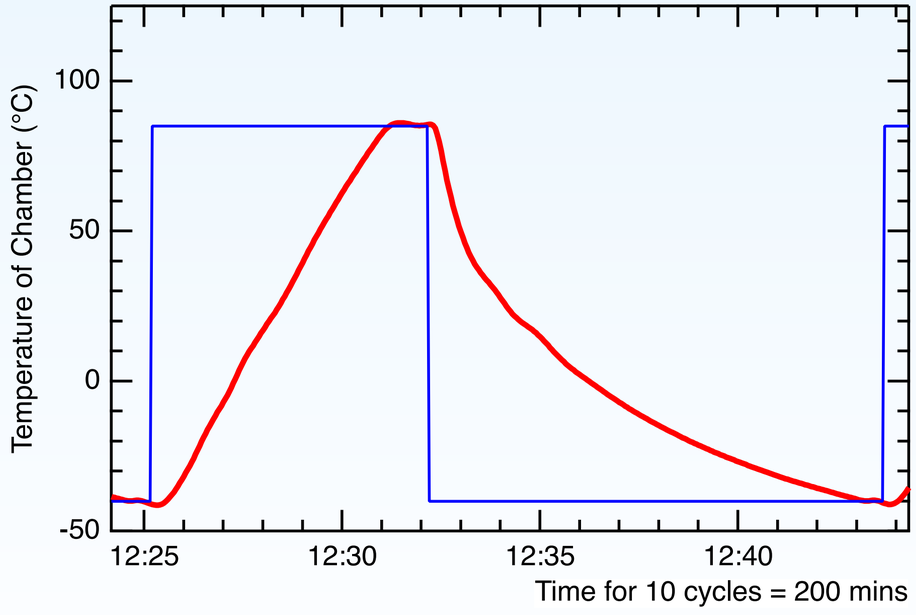
- Simple fix possible with “white wire”
  - Applied to all boards in April 2015

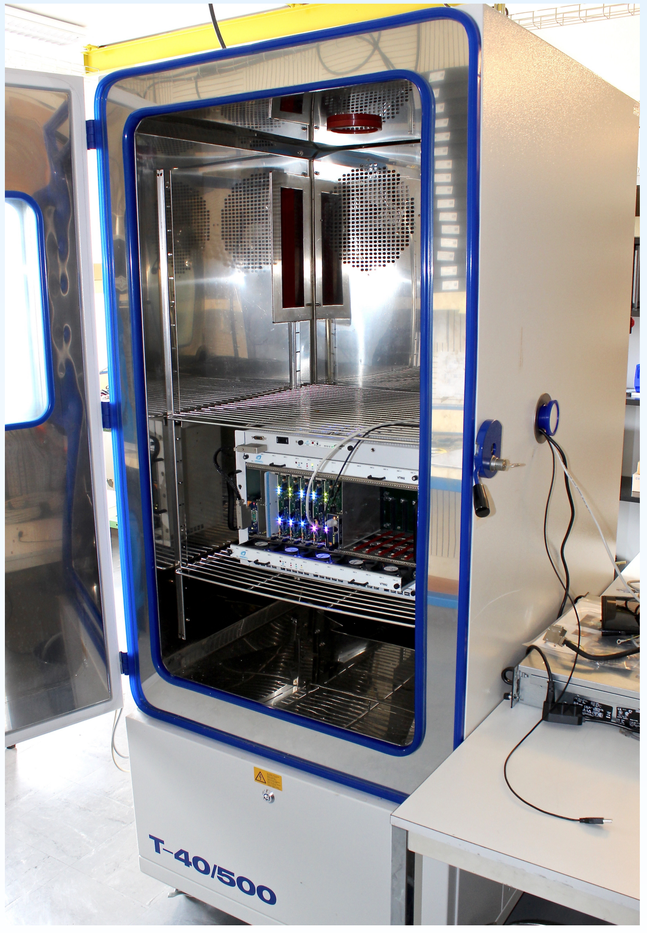
Medium/Long-term mitigation strategy

- All installed FC7s at P5 were replaced with boards that had not been powered at incorrect voltage
  - No guarantee that devices previously operated with EOS would continue to survive
  - Relied on existing spares available within TCDS and made available by other projects
  - Ordered 30 new boards with existing design and immediately applied white wire fix
- Prepared to replace full population with stable production version of FC7 when available
  - FC7 R2 included required voltage fix
  - Need to validate FC7 R2 design very carefully to validate success of the fix!
  - R2 first batch delivered Dec. 2015

FC7 R2 Validation

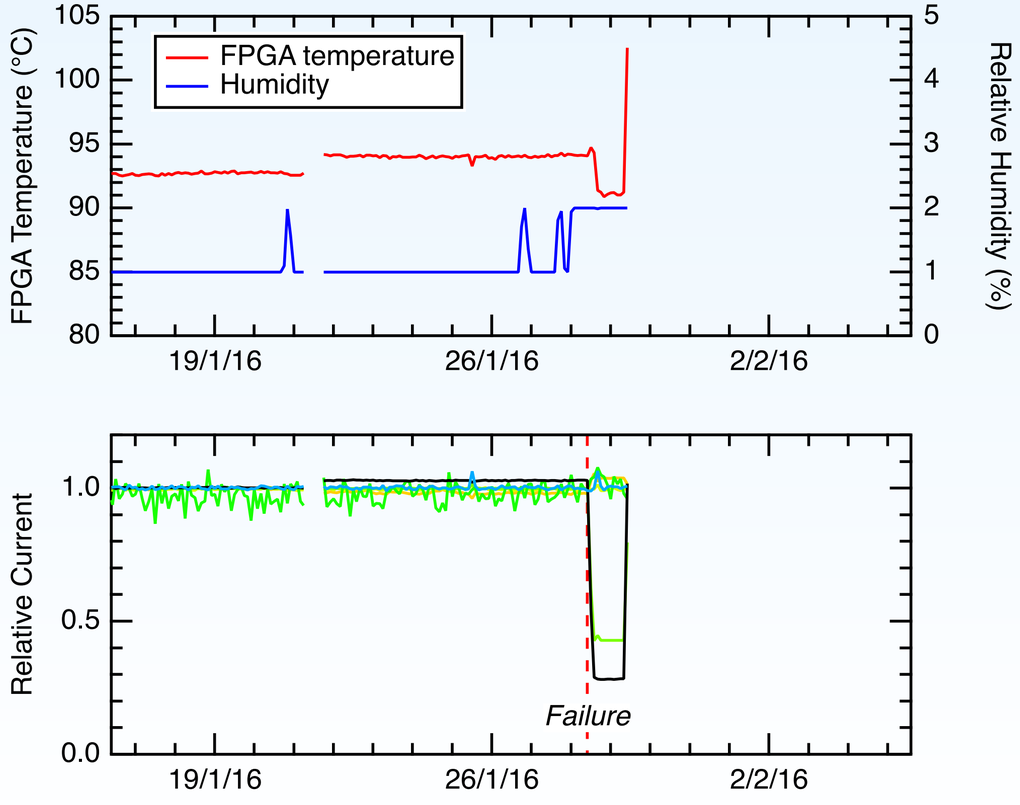
- QA programme carried out on 5 R2 boards and 1 unmodified R1 board:
  - Temperature Cycling: -40 to +85 °C, 500 cycles
    - Measurements at 100, 200, & 500 cycles
  - High-temperature Operating Life (HTOL): ~95 °C, >500 hrs
    - Lifetime acceleration factor of 54-78 with Xilinx recommended activation energy of 0.7 eV





EOS acceleration?

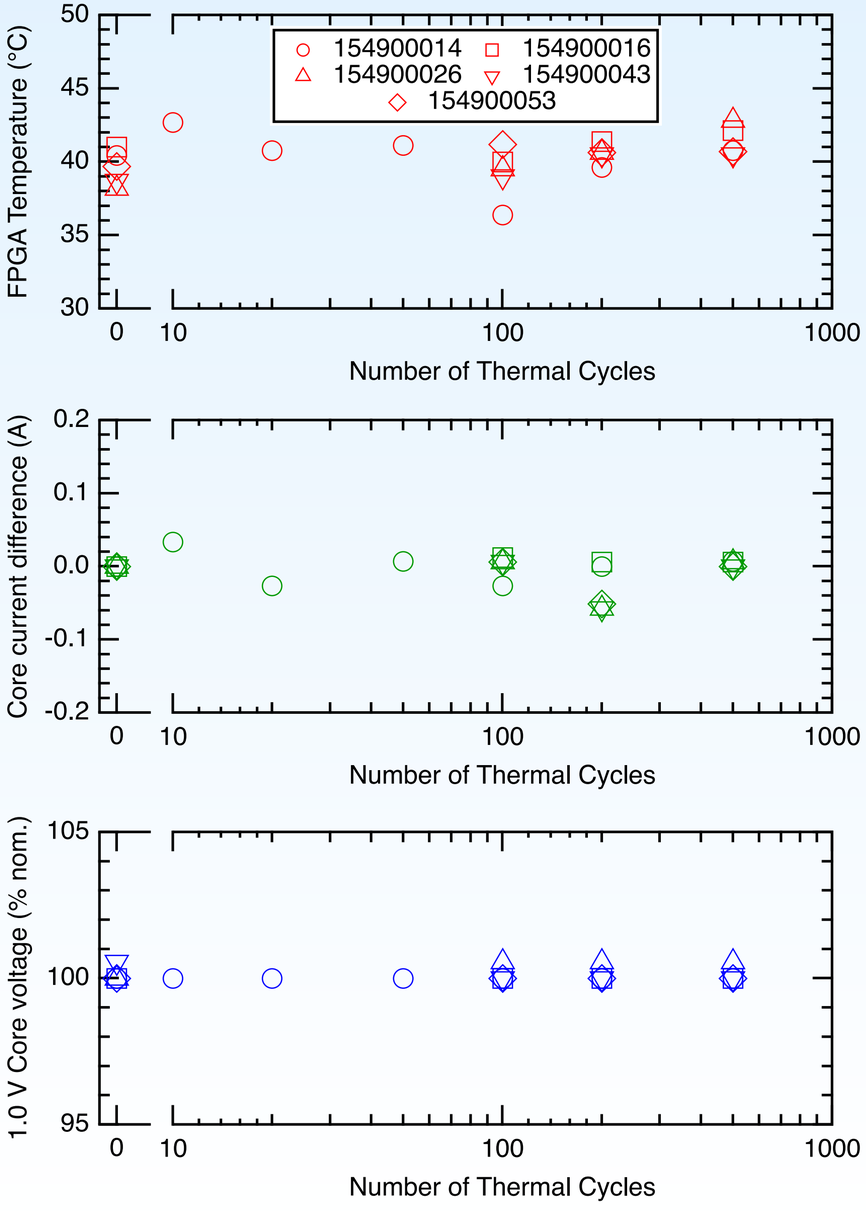
- As a cross-check, HTOL carried out also with FC7 R1 without white-wire fix
- Failure observed after approx. 300 hrs
- Same failure signature as observed in CMS

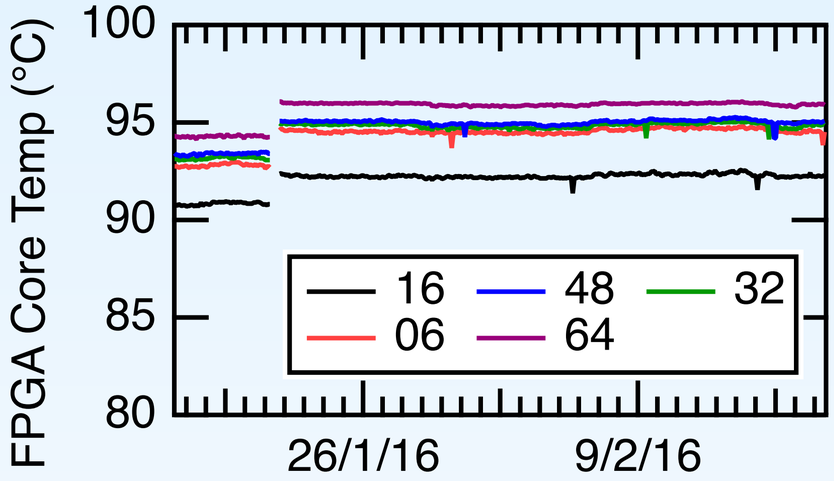


- Acceleration factor found to be lower than expected for 0.7 eV activation energy
  - Calculated 0.5-0.6 eV, compatible with literature

Had we done this kind of QA up-front, would not have suffered a nail-biting six months waiting for everything to fail…

FC7 R2 Validated





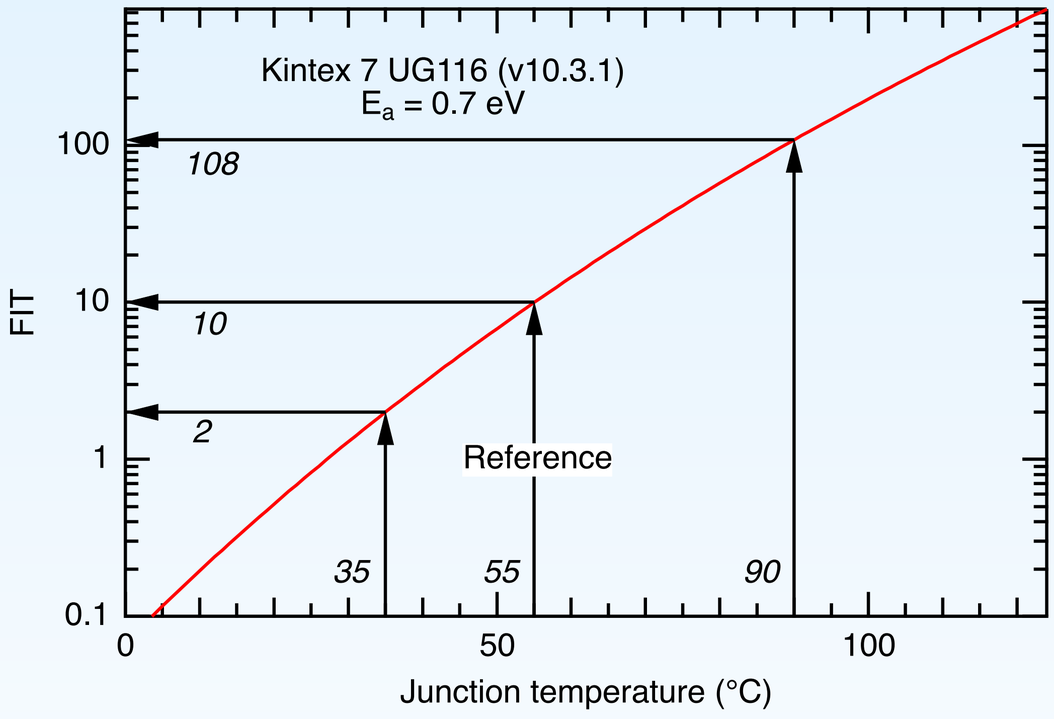
- No significant changes observed in either T-cycling or HTOL tests
- Accumulated 25 device-years of effective operation
- FC7 declared ready for deployment in Feb. 2016
  - 17 months after TCDS installation…

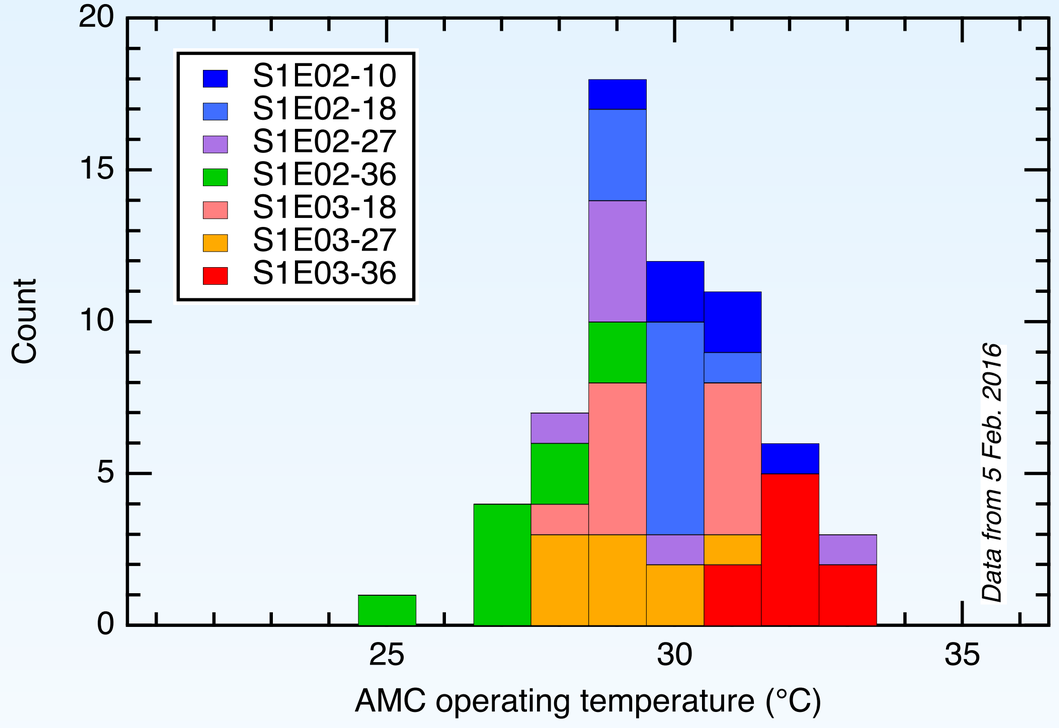
Summary

- CMS TCDS system installed during LS1
  - based upon µTCA system with FC7 AMC
- Suffered high-level of in-situ failures after a few months of operation
- AMC Sensor monitoring data very useful to track problems
- Full device Failure Analysis needed to solve problem
  - We do not have such facilities within the community, must rely on good relationships with vendors
- QA programme like the one typically required of the front-end electronics put in place to validate final board revision
  - Should foresee such tests for all custom electronics
  - Even if they are accessible, facing a complete failure of a central system critical to the operation of an experiment is very uncomfortable! Diagnosis always takes time…
  - Must allow time in development plans for this step, which can take several months (longer in case of problems)

Backup

HTOL Acceleration Factor





- Device temperature measured in-situ in CMS, take 35 °C as conservative maximum value
- Acceleration factor 90 °C w.r.t. to operation is ×54