The CMS Tracker Front End Readout Electronics

James Leaver, Imperial College, IOP HEPP Conference 2005

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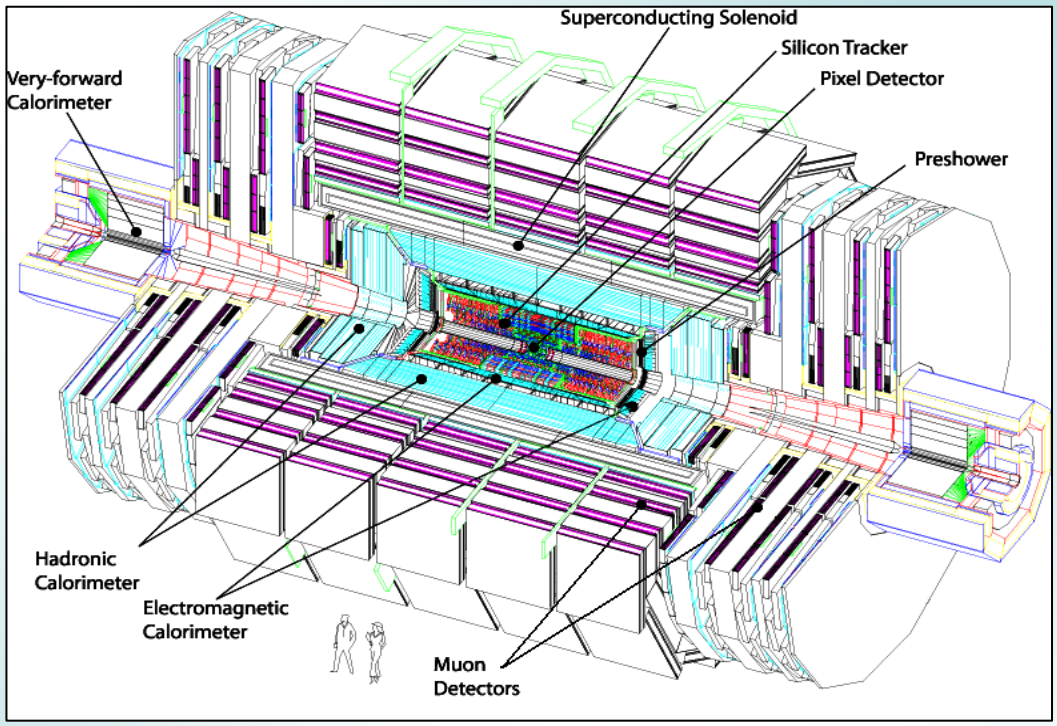
The Compact Muon Solenoid



Solenoid — Based upon a 4T solenoidal magnet – the largest ever built

Compact — Solenoid is so large that all tracking devices & calorimetry can be placed inside

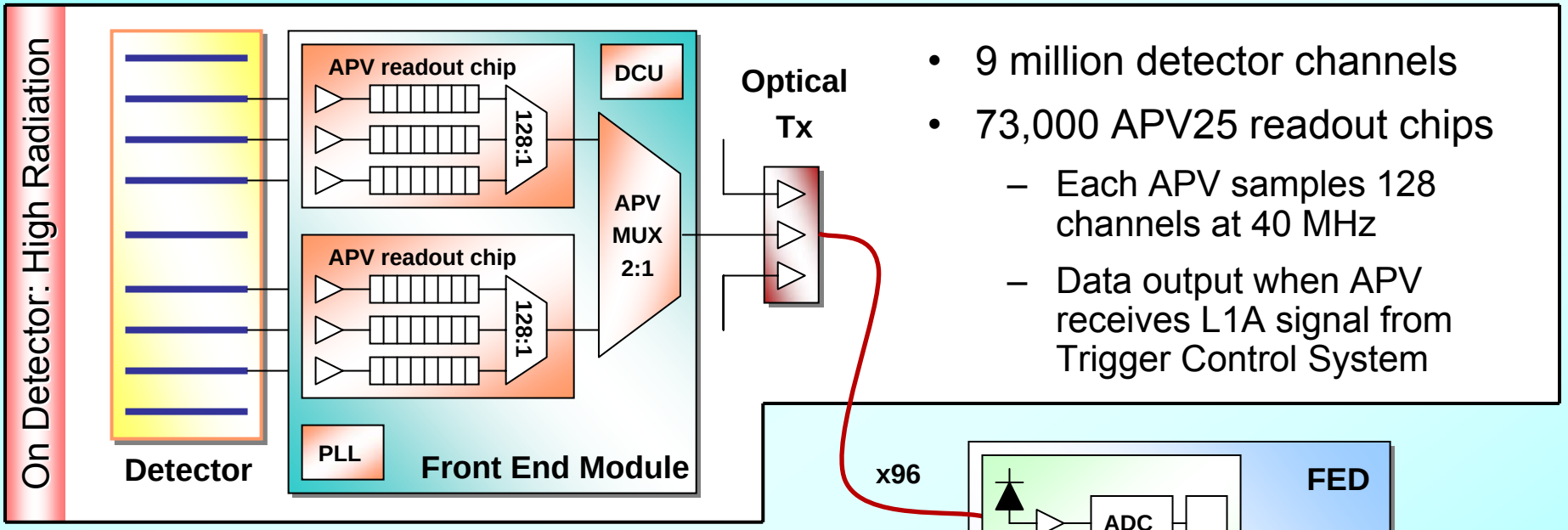
Muon — Emphasis on detecting Muons (Muons expected to provide clean signatures for a wide range of physics processes, e.g. $H \rightarrow ZZ(*) \rightarrow 4\mu$)

- General purpose detector for the CERN LHC
- Designed to study p-p (14 TeV CM energy) & Pb-Pb collisions (1.3 PeV CM energy)
- Particle bunches cross at 40 MHz $\Rightarrow 10^9$ Hz interaction rate at p-p luminosity ($10^{34}cm^{-2}s^{-1}$)
- 100 Hz of interactions recorded (data reducing trigger system)

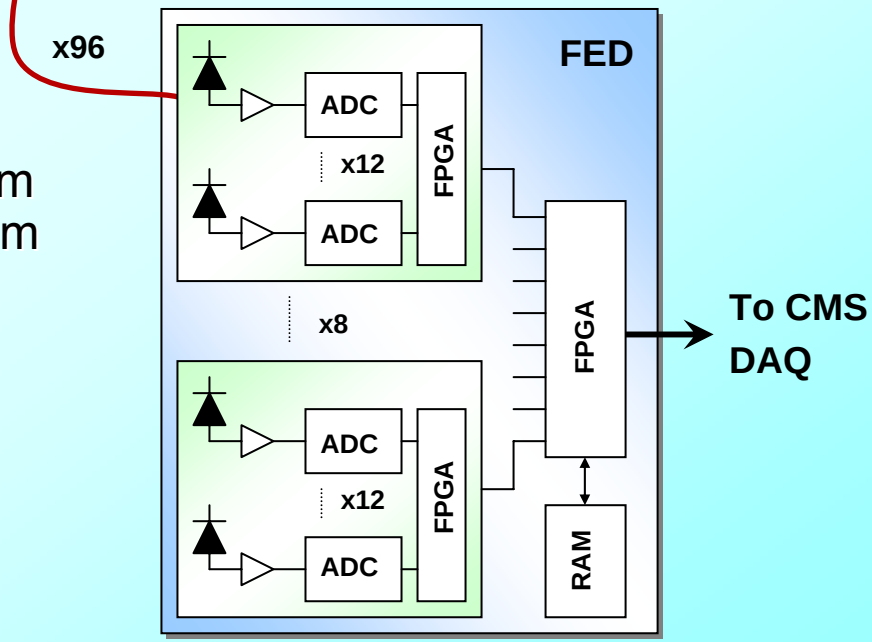
Design goals:

- A high performance redundant Muon system
- The best possible Electromagnetic Calorimeter
- A hermetic Hadron Calorimeter with good energy resolution
- A high quality central Tracking system

Silicon Tracker Readout System

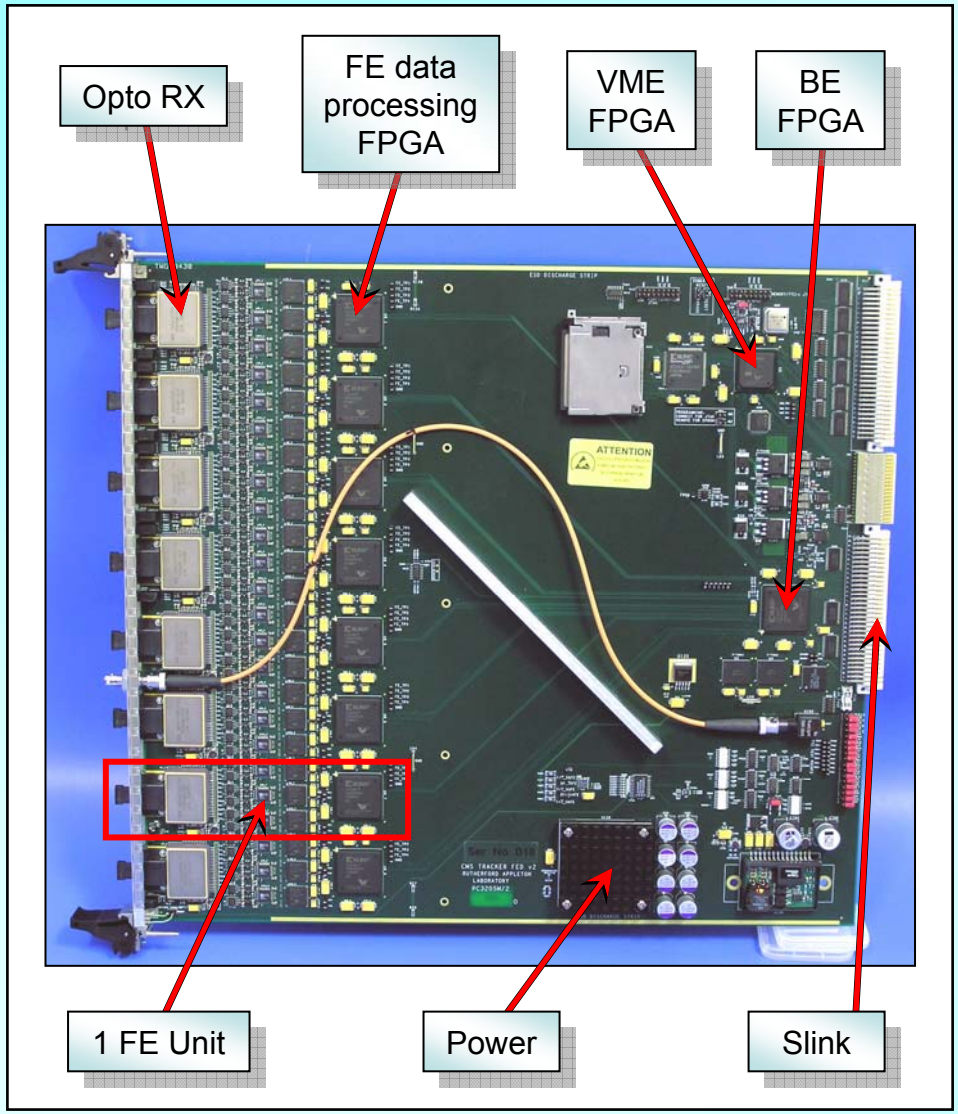


- 9 million detector channels
- 73,000 APV25 readout chips
  - Each APV samples 128 channels at 40 MHz
  - Data output when APV receives L1A signal from Trigger Control System



- Analog data transmitted optically via 100m links to Front End Drivers in counting room
  - 43,000 optical readout links
  - 1.3 TB/s @ 100 kHz L1As
  - 440 FEDs
- FED reduces immense data volume to level with which the CMS DAQ can cope

The Front End Driver

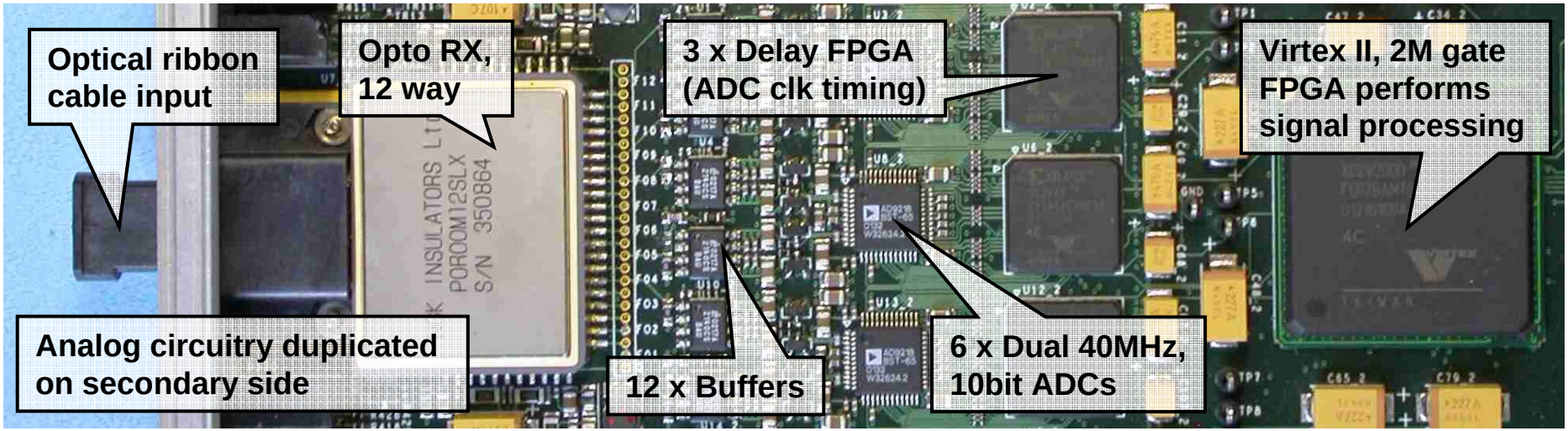


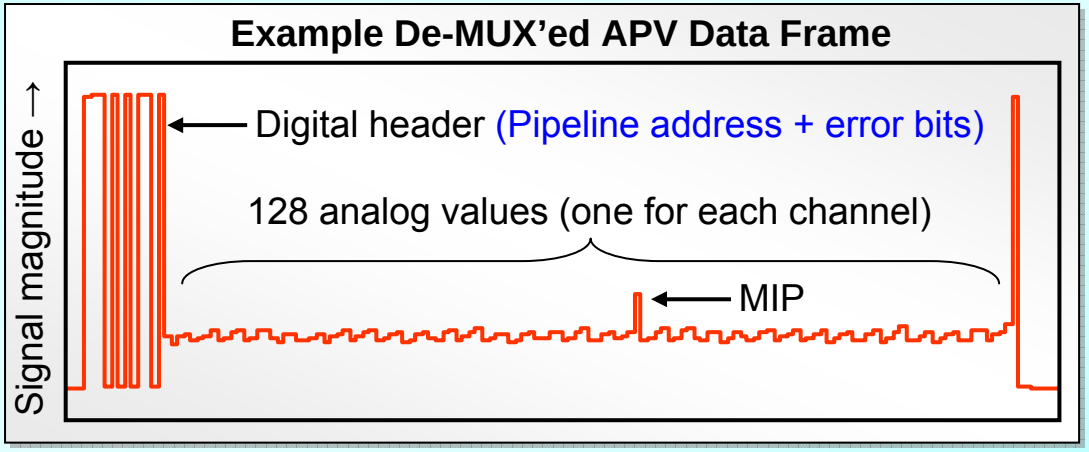
- Input = 96 optical fibres, each from a MUX'ed pair of APVs
- Input data rate = ~3.4 GB/s
- 8 Front End Units perform data reduction ('Zero Suppression')
- Back End FPGA collects FE data & builds events
- Events output using Slink 64 protocol (high-capacity link)
- Output data rate = ~50 Mb/s per % of Tracker occupancy

High density, high performance board, at the cutting edge of PCB design

The FED Front-End

Optical | Optical to electrical | Analog to 10bit digital | Clock phase | Cluster finding





To extract hit information, need:

- Data Synchronization and reordering
- Pedestal subtraction
- Common mode noise subtraction
- Cluster (hit) finding

FED Production Testing

0. Quality Controls during Assembly process AOI, X-ray

1. Custom Tests at Assembly Plant BScan, VME crate

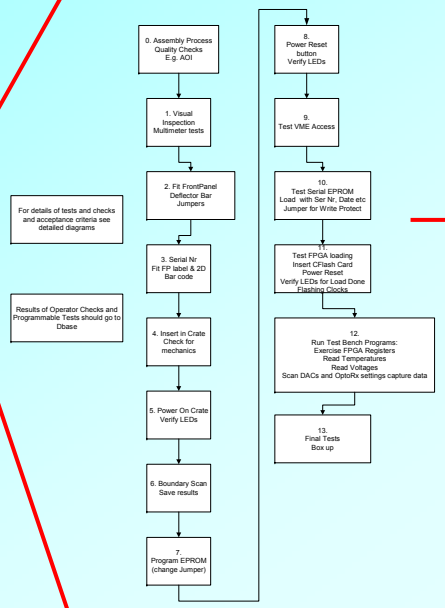
2. Tests at RAL & IC OptoRx, Full crate

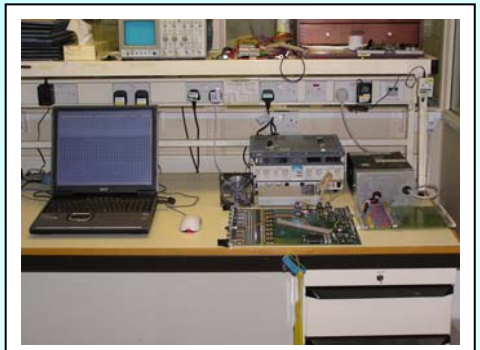
3. Tests at CERN Prevessin 904 Readout Integration

4. Installation at CMS USC55

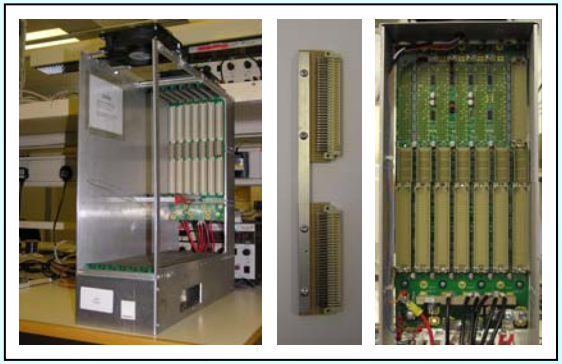
Test Flow from Assembly Plant to USC55.

500 boards to test over 10 months





Manual testing by Assembly Plant operatives

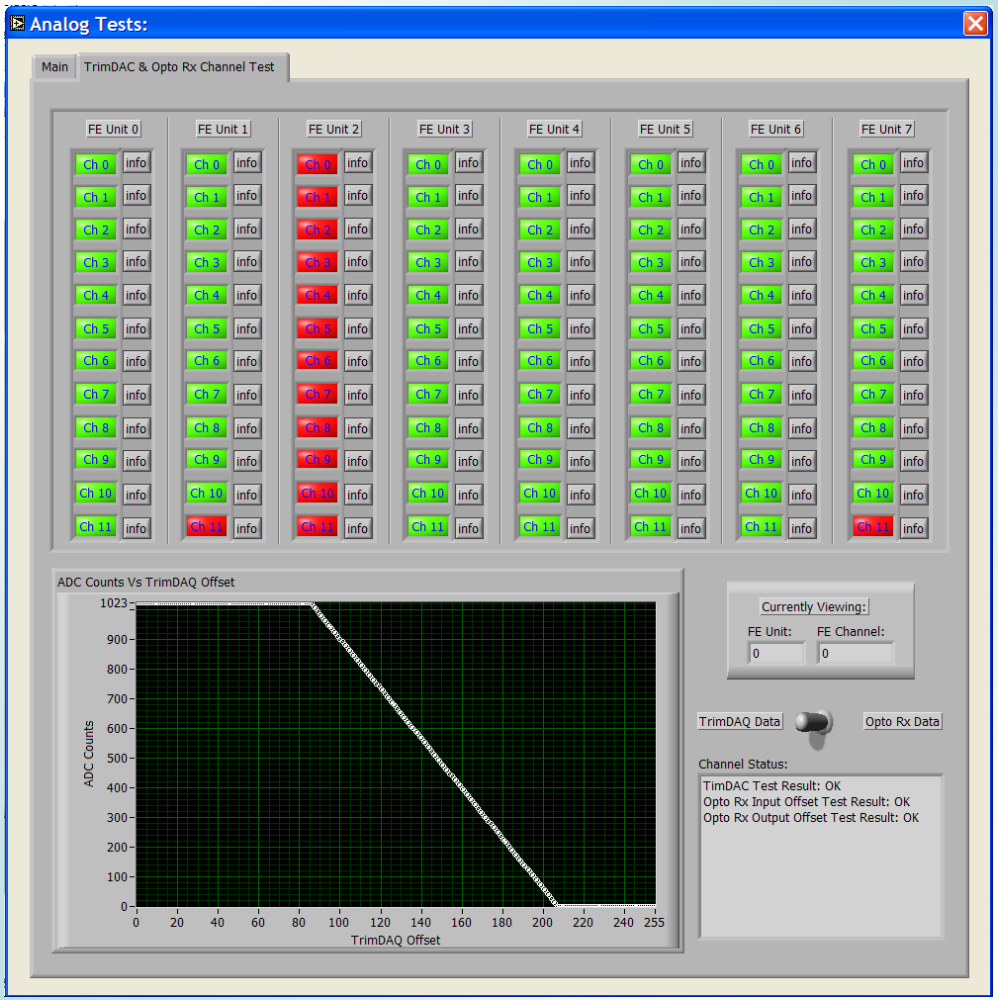


Boundary Scan testing for digital connectivity

\+ VME Crate Testing for Digital & Analog functionality, using custom software suite

- Essential to catch manufacturing errors as soon as possible
  - Detailed custom test procedure at Assembly Plant
- Plant operatives require user-friendly FED Acceptance Testing Software

Acceptance Testing Software



Example Test Page (12 pages in total)

- Simple push-button controls
- Fully automated testing of digital functionality & analog readout path
- Automated generation of XML/HTML results database

Example Results Pages

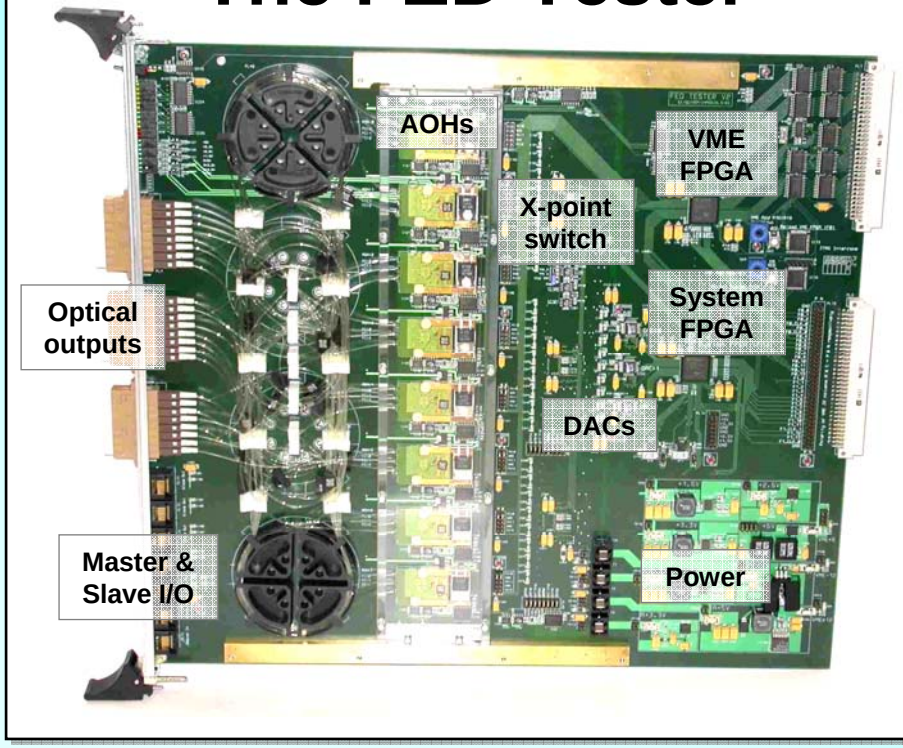
FED Production Timeline

2003 – Q1	Manufacture first 2 FEDv1s → Express/SAETech - Initial testing
2003 – Q2	Manufacture 3 more FEDv1s → Express/SAETech
2003 – Q4	Manufacture 6 FEDv1s → Express/SAETech - Many serious manufacture errors
2004 – Q1	Manufacture 6 FEDv1s → DDi - Complete tests of Prototype FEDv1 design
2004 – Q2	Implement changes for FEDv2 and review
2004 – Q3	Manufacture first 2 FEDv2s → DDi - Dispatch calls for final manufacture quotes
2004 – Q4	Test initial FEDv2s - Select DDi for final job; negotiate testing, schedules, etc.
2005 – Q1	Manufacture another 25 FEDv2s → DDi - Award contract for final job to DDi
2005 – Q2 to 2006 – Q2	Manufacture 500 FEDs (~50 per month) → DDi (now eXception) - Fully test batches in UK - Re-test at CERN prior to CMS installation

Laboratory Testing of the FED

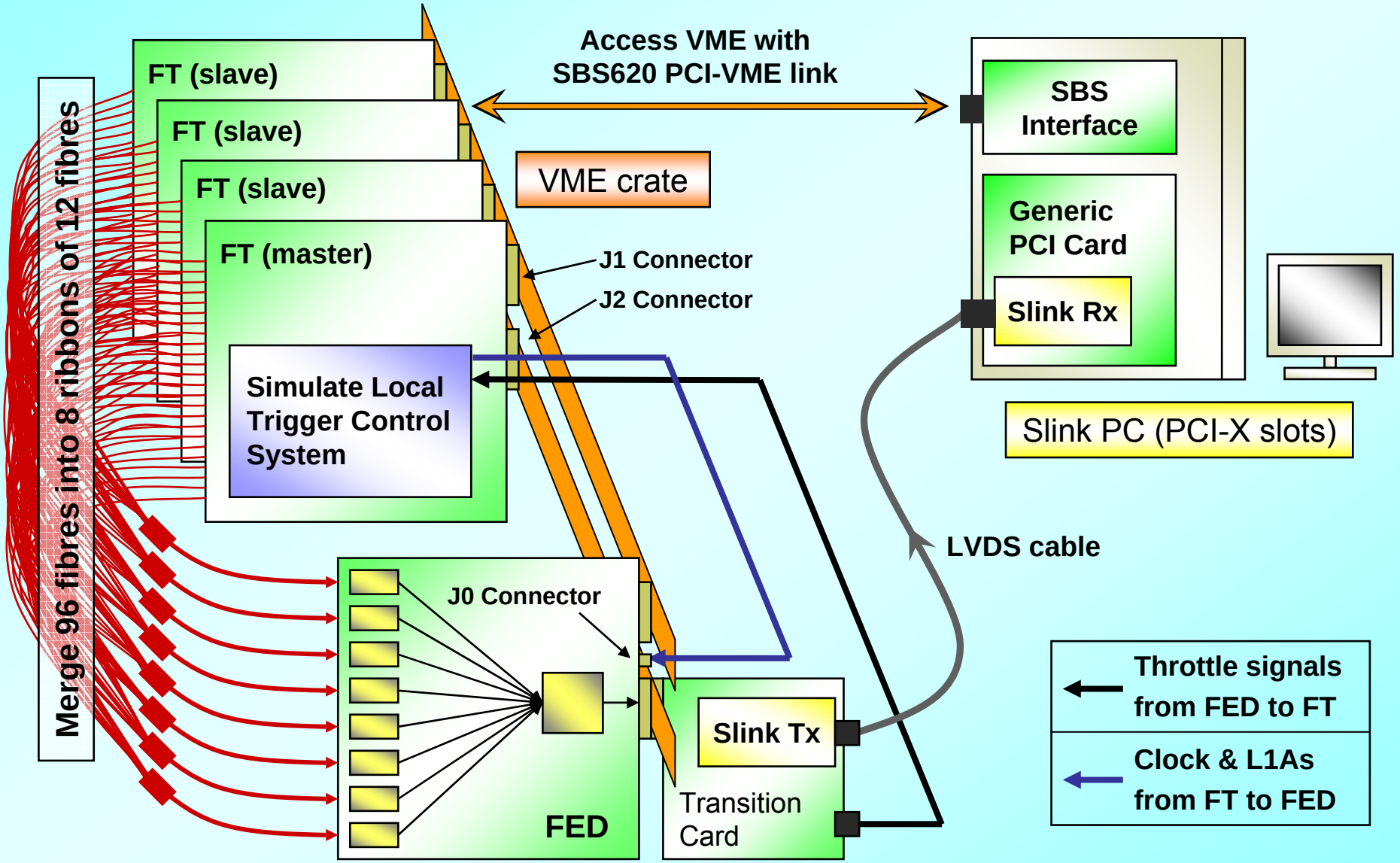
Testing the FED with optical input under realistic CMS conditions requires custom hardware:

The FED Tester

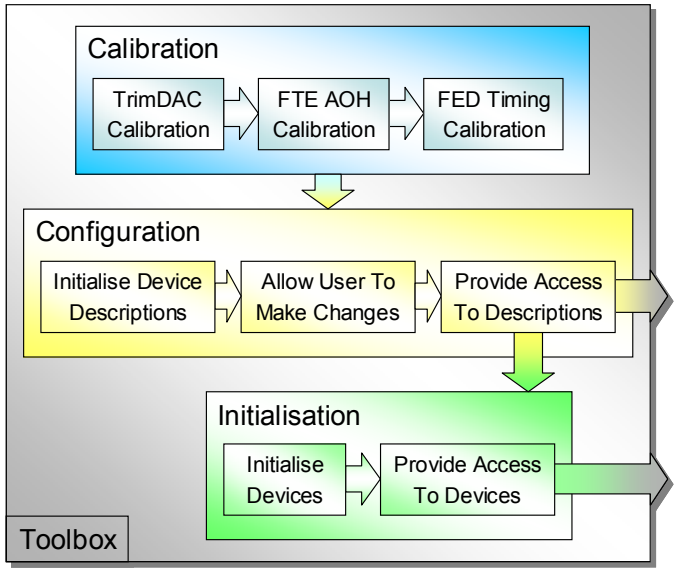


- Emulates Silicon Tracker optical data
- Test data loaded via VME to on-board SRAMS
- Data converted to analog via 3 DACs
- 8 CMS Analog Optical Hybrids convert analog data to optical format & drive the FED
- 24 Optical Outputs → 4 FED Testers required for one FED

Full System Tests



FED Tester Software



- Extensive software development:
  - One function to calibrate, configure & initialise entire system
  - One object to access all hardware & software elements
  - Supports any number of FEDs & related hardware items (currently test one FED at a time)

Comprehensive test suit built around core framework – have verified that:

- Every input detector hit is correctly identified (under realistic CMS conditions)
- FED channel noise is < 1 ADC count
- FED inter-channel crosstalk is < 1% of signal amplitude on neighbouring channels (next-nearest neighbours unaffected)

Can perform rigorous error checking on billions of events, processed at highest CMS data rates

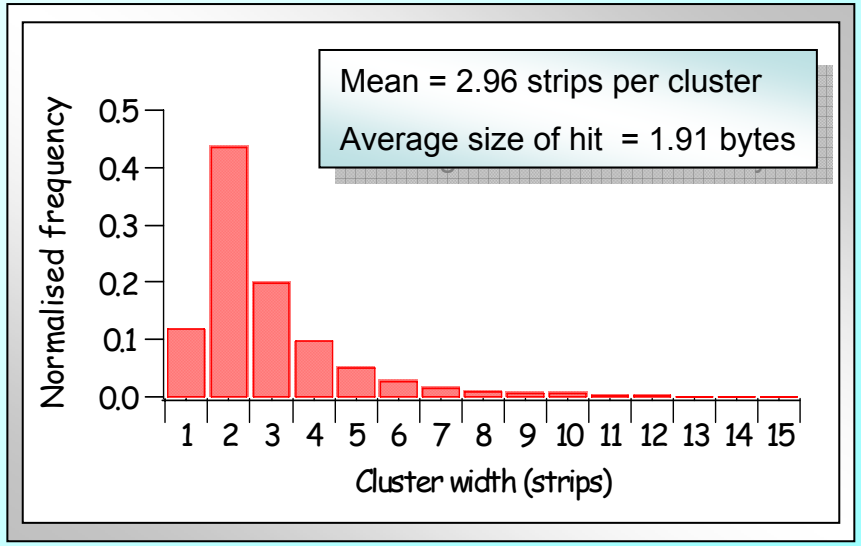
Measurement of Deadtime Vs Tracker Occupancy

Emulated CMS operating conditions:

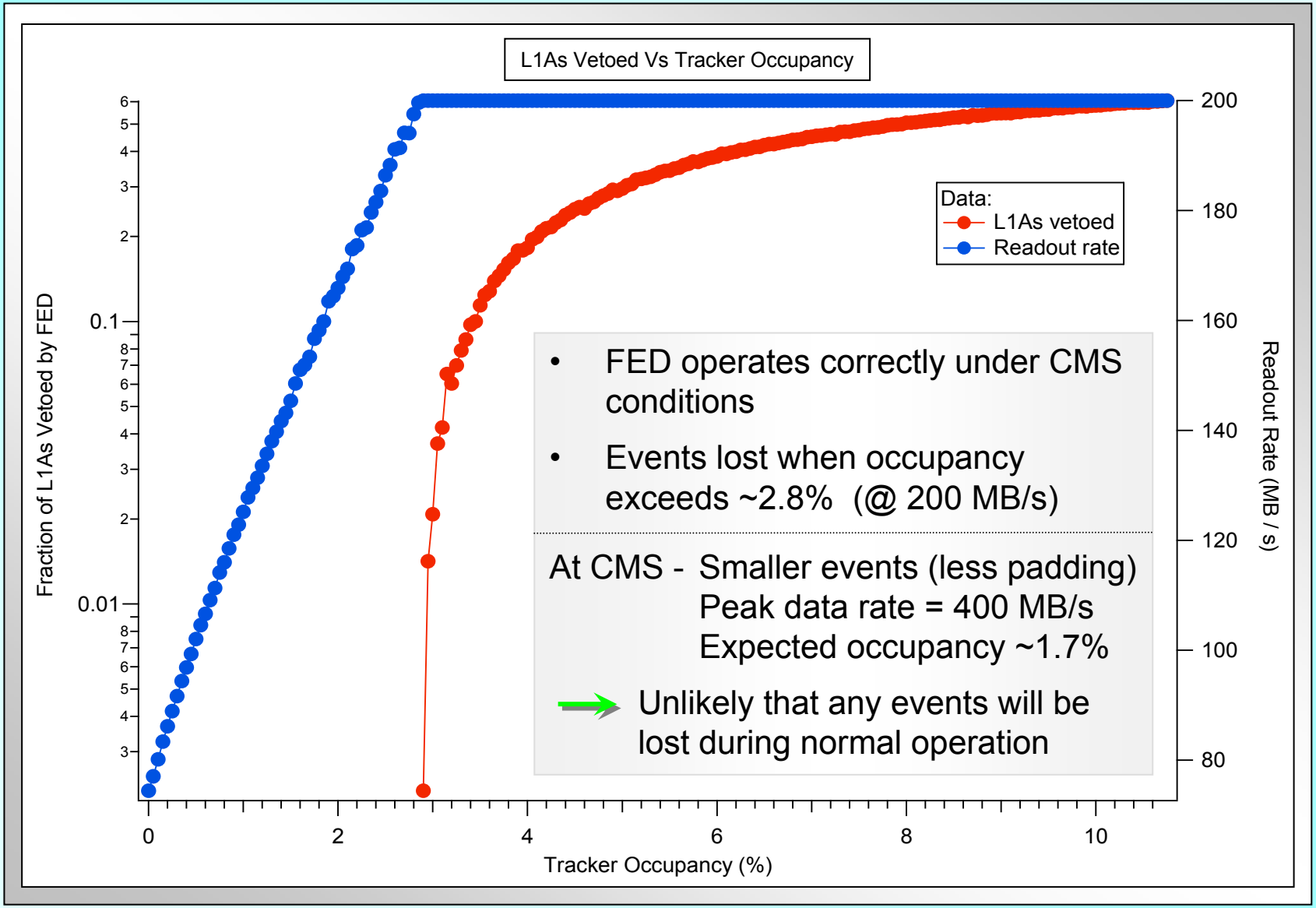
- Random 100 kHz triggers
- Readout rate through Slink limited to maximum of **200 MB/s**
- Randomly generated events with **simulated CMS cluster distribution** sent to FED
- Measured fraction of events vetoed by FED as a function of detector occupancy

- 1 Slink receiver accepts data from 2 FEDs
- Peak data rate = 400 MB/s
- Assumed that each FED transmits equal data volume…
- …But in practice, high & low occupancy FEDs will be paired

Simulated cluster distribution generated from the CMS-IN 2001/025 Note: "On Calibration, Zero Suppression Algorithms and Data Format for the Silicon Tracker FEDs"



Deadtime Vs Tracker Occupancy: Results



Summary

- **The CMS Tracker Readout Electronics:**
  - The FED is a vital component of the CMS Tracker
  - Provides the link between detector & CMS DAQ
- **FED Assembly:**
  - Manufacturing schedule is on time
  - Rigorous testing procedures should ensure that manufacturing faults are discovered before FEDs leave the Assembly Plant, minimising potential delays
- **FED Performance Testing:**
  - Framework in place for current and future FED testing procedures
  - FED has been successfully tested under realistic CMS operating conditions, no significant problems found