Calibration and Quality Control of the CMS Triple-GEM Detectors

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21 December 2018

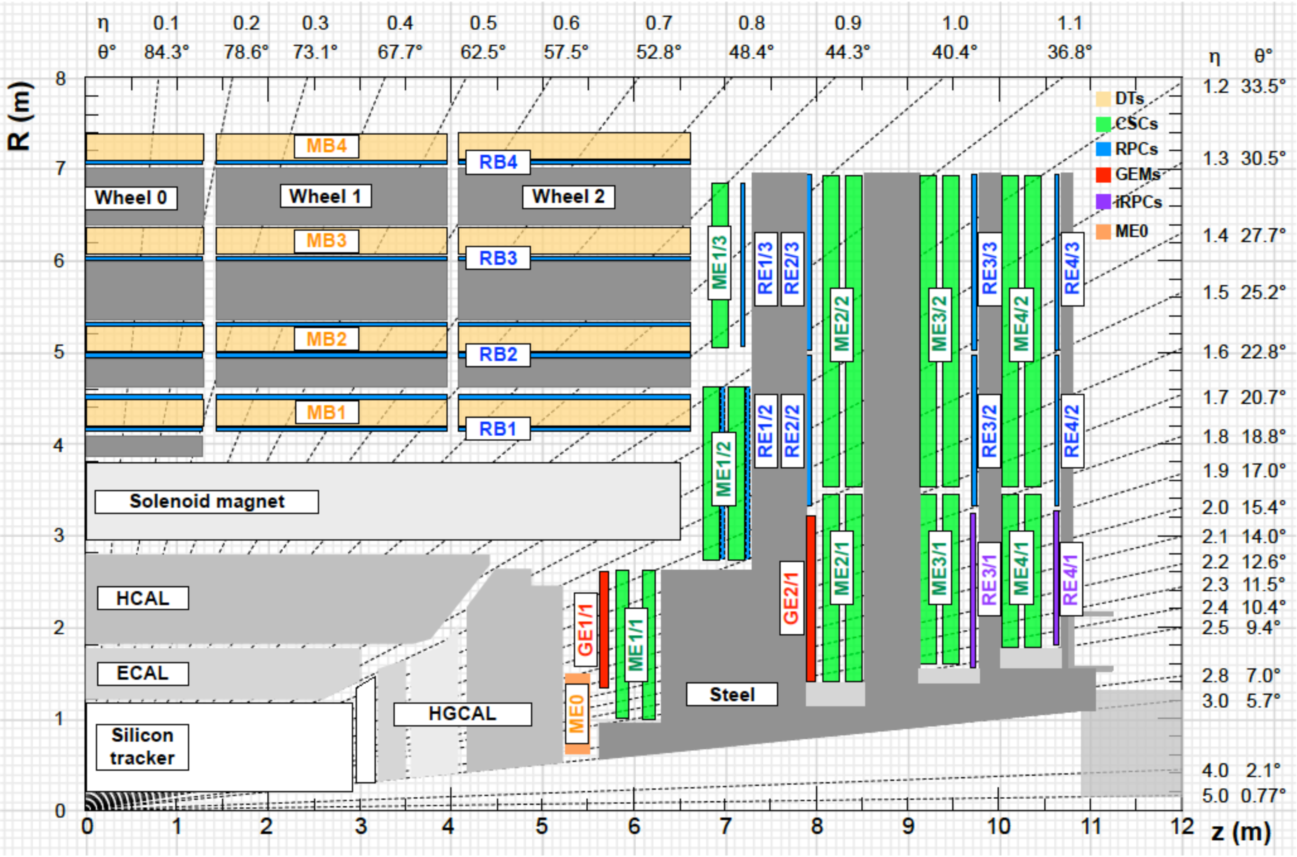
CLHCP 2018

Introduction

- A triple-GEM detector uses 3 parallel GEM (gas electron multiplier) foils for successive avalanches
- Triple-GEM technology has been used successfully in many other experiments, including COMPASS and LHCb at the LHC
- In order to cope with higher instantaneous luminosities, the CMS Collaboration is preparing to add triple-GEM detectors with both tracking and triggering capabilities
- This talk will focus on the final stages of quality control and calibration, and the front-end and back-end readout electronics

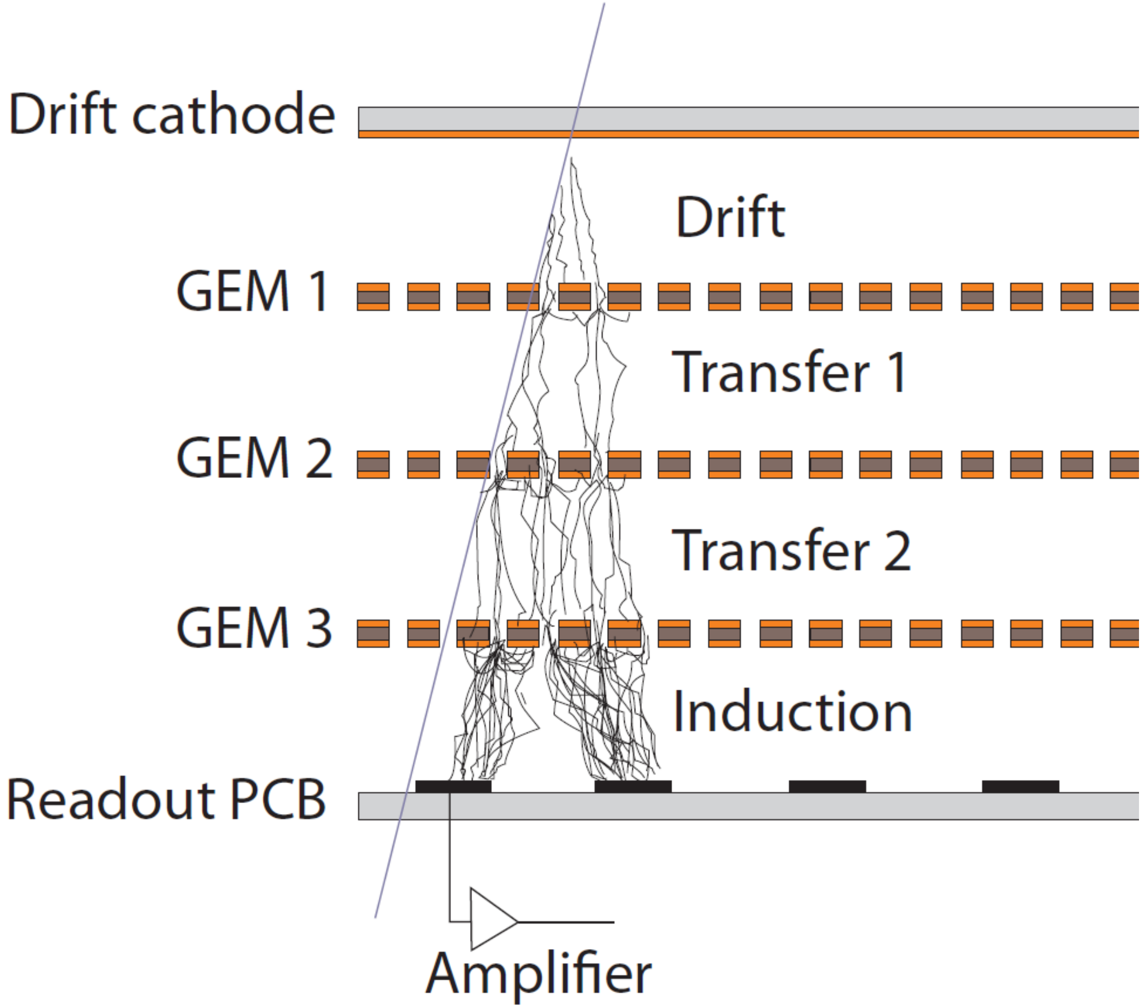
Use in CMS

- Will be installed in GE1/1 during the long shutdown that just started
- GE1/1 is the innermost ring of the muon layer closest to the interaction point
- Will be installed on both positive and negative z
- 144 chambers will be installed
- Later will be installed in GE2/1 and ME0



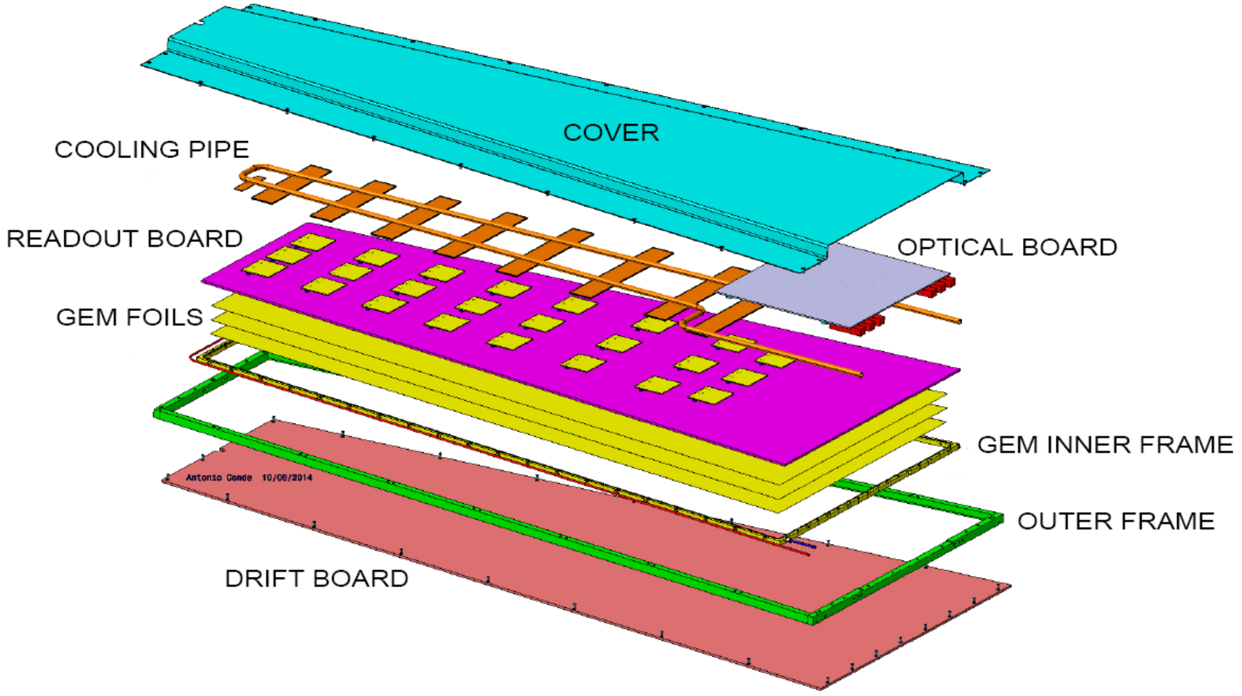
Principle of operation

- Four gas-filled gaps separated by thin foils with small holes
- High-voltage difference, on the order of 1 KV, applied to each gap
- Incoming muon ionizes electrons in the drift gap
- Electron multiplication factor of around 20 at each GEM foil
- Charged collected at the bottom of the induction gap in strips



Chamber design

- Gaps between GEM foils are 1-3 mm
- Trapezoid shape, two types: short and long
  - Short: 106 cm long and 23 – 42 cm wide
  - Long: 121 cm long and 23 – 44 cm wide
- 24 ASICs called VFATs on the readout board to cover the entire chamber
- Two chambers are combined to form a super-chamber

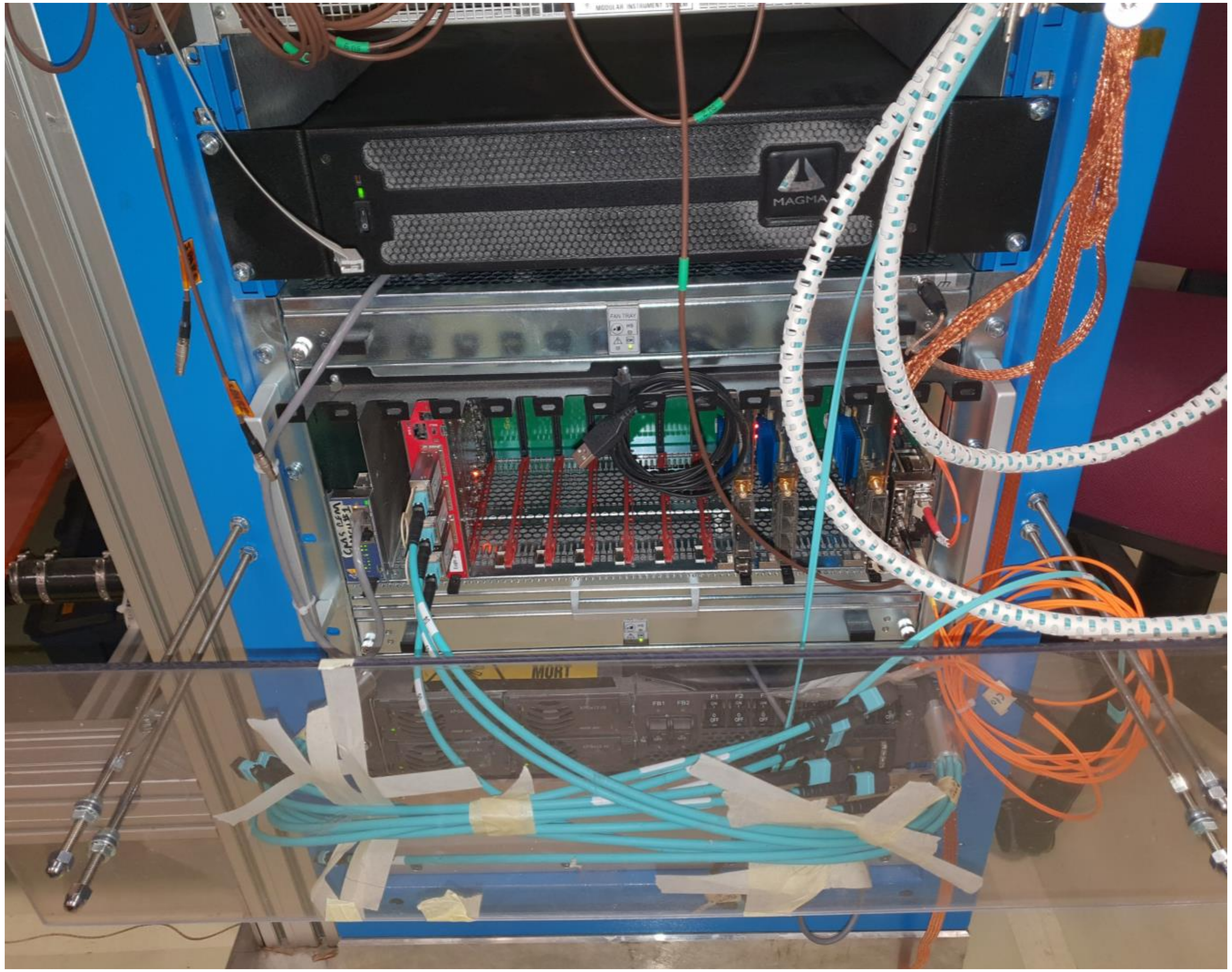


Quality control and calibration

- Quality control (QC) sequence:
  - QC1/QC2: Material inspection and GEM test
  - QC3: Gas leak test
  - QC4: High-voltage test
  - QC5: Gain uniformity test
  - QC6: High-voltage stability test
  - QC7/QC8: electronics connectivity test/ cosmic ray data taking, example photo on right
- Parameters to be calibrated:
  - VFAT DAC registers
  - Voltages between the gaps
  - Readout latency
- Current status
  - Super-chamber assembly has started and will soon produce enough super-chambers to fill up the cosmic stand on the right

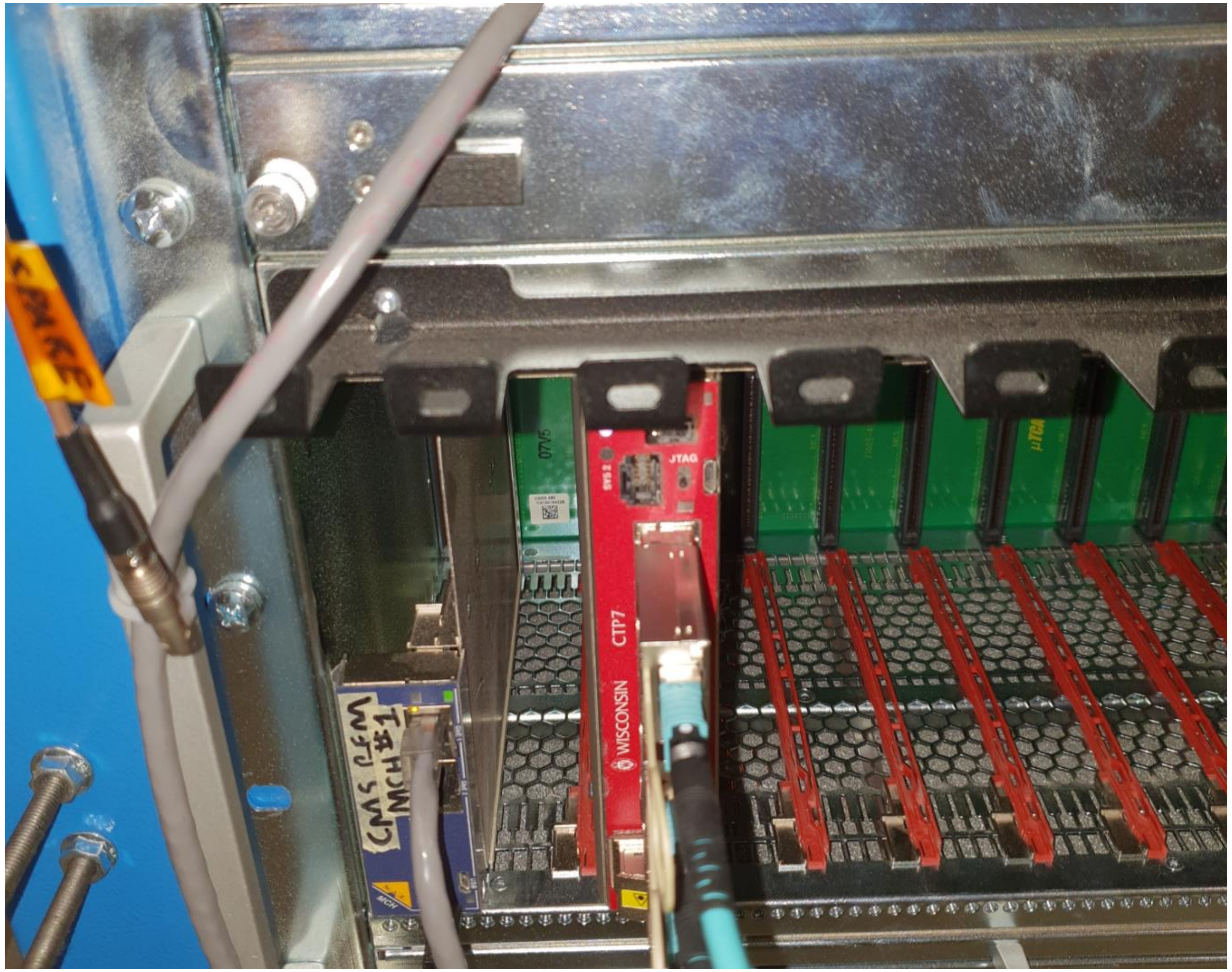
Overview of data acquisition

- µTCA crate (shown on the right) has 12+1 slots
- Slot 13 is for the AMC13, which interfaces the CMS central DAQ, and provides level 1 trigger signals to the other 12 slots
- Real data taking chain: VFAT -> Optphybrid -> AMC (=CTP7) + AMC13 -> CMS central DAQ
- Slow control chain: PC --> AMC (= CTP7) --> Optohybrid --> VFAT



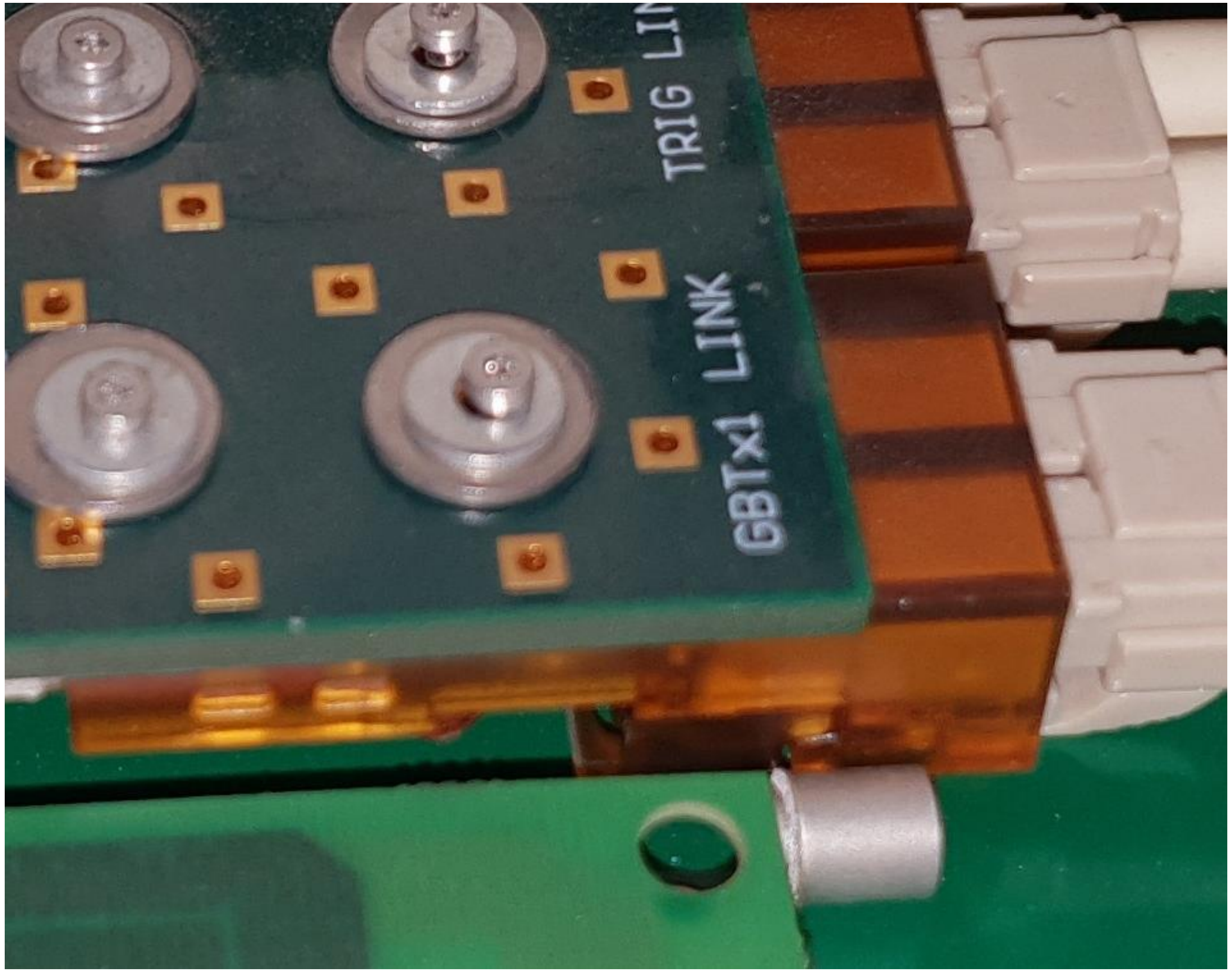
CTP7

- Calorimeter Trigger Processor (originally used for CMS calorimeter)
- Optical link receiver and transmitter
- Contains an FPGA and a processor which runs a special version of Linux



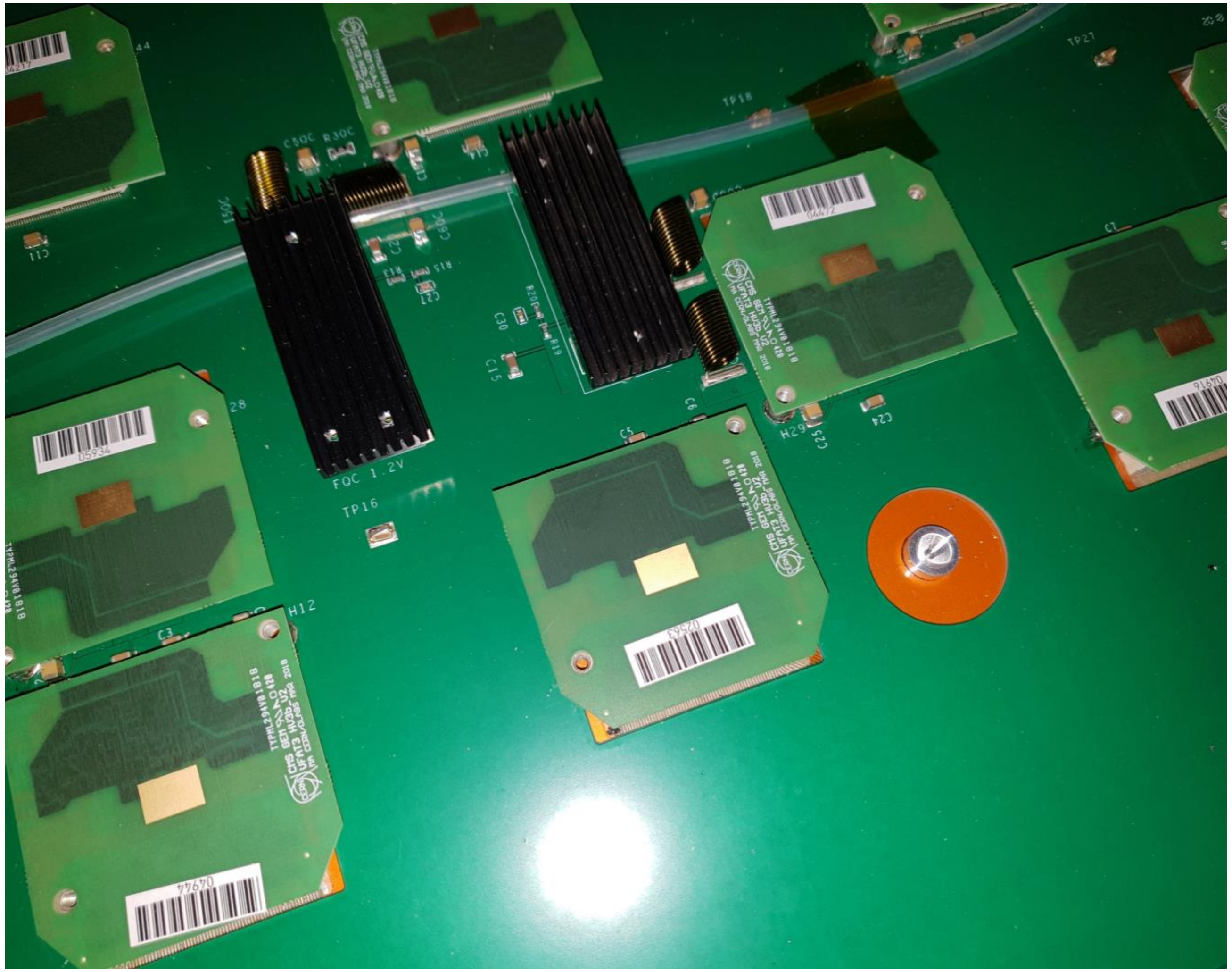
GBTX

- Gigabit transceiver
- Optical link receiver and transmitter
- 3 GBTXs needed to handle all of the communication from the VFATs, the FPGA, and the SCA
- GBTX chip is fused initially using USB “dongle”, and then some registers, such as the phases, can be adjusted remotely



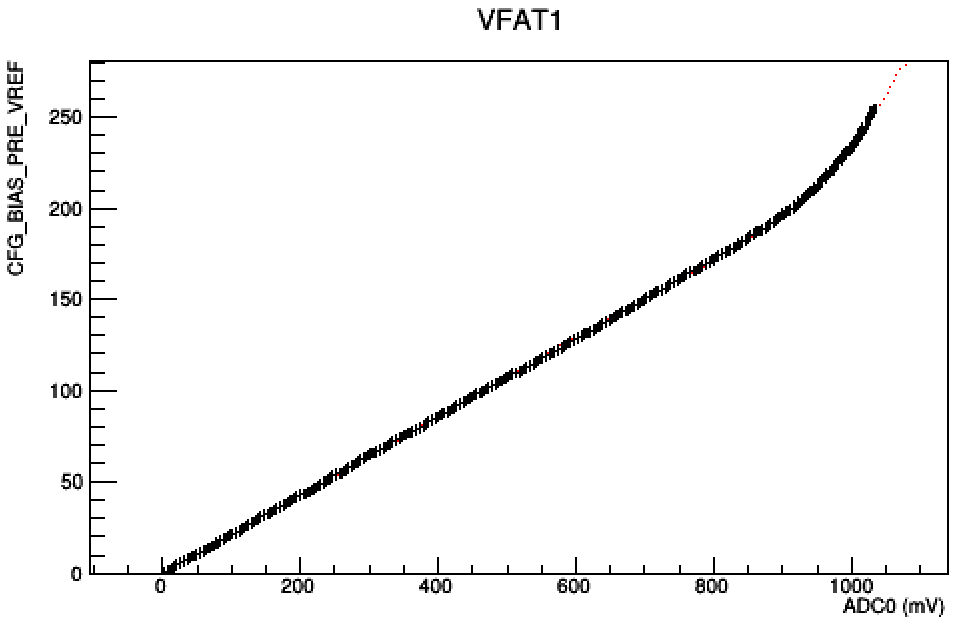
VFAT3

- 128 channels corresponding to 128 strips in the chamber
- A “DAC” is programmable register in the VFAT
- 18 global DAC registers
    - Control the charge amplification, charge shaping, bias current, and other things
    - Global threshold register (arming comparator)
- 128 DAC registers for per-channel threshold adjustment
- Configurable per-channel calibration pulse generator



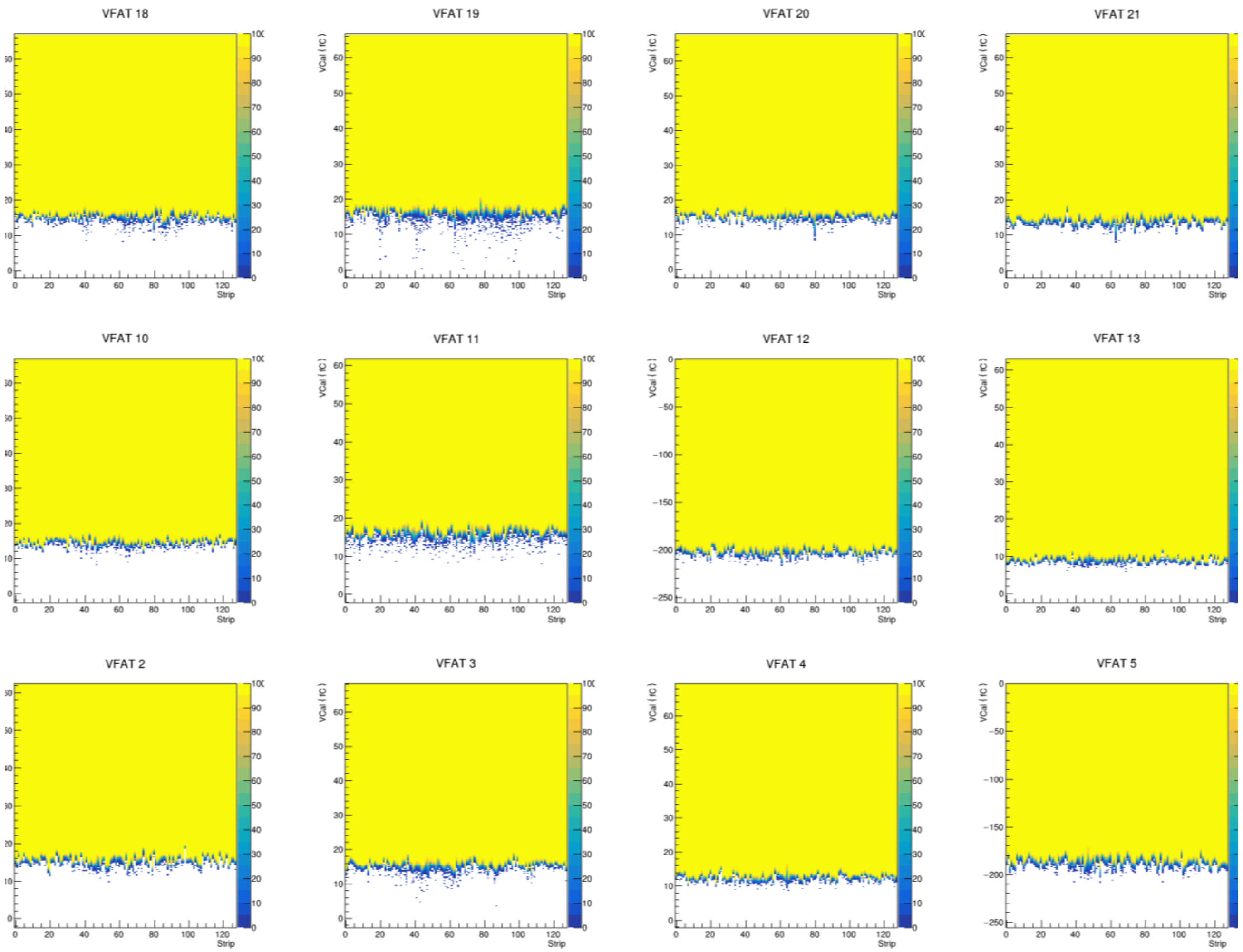
DAC scans

- Due to radiation, the appropriate DAC settings may change
- Record the ADC value for each possible value of the DAC register
- ADC is converted to a voltage or a current using calibration information provided by the VFAT3 designers
- DAC vs ADC plot can be fit with a 5th degree polynomial
- From this plot, we can determine the DAC register setting that corresponds to the nominal value of the ADC, which is also provided by the VFAT3 designers



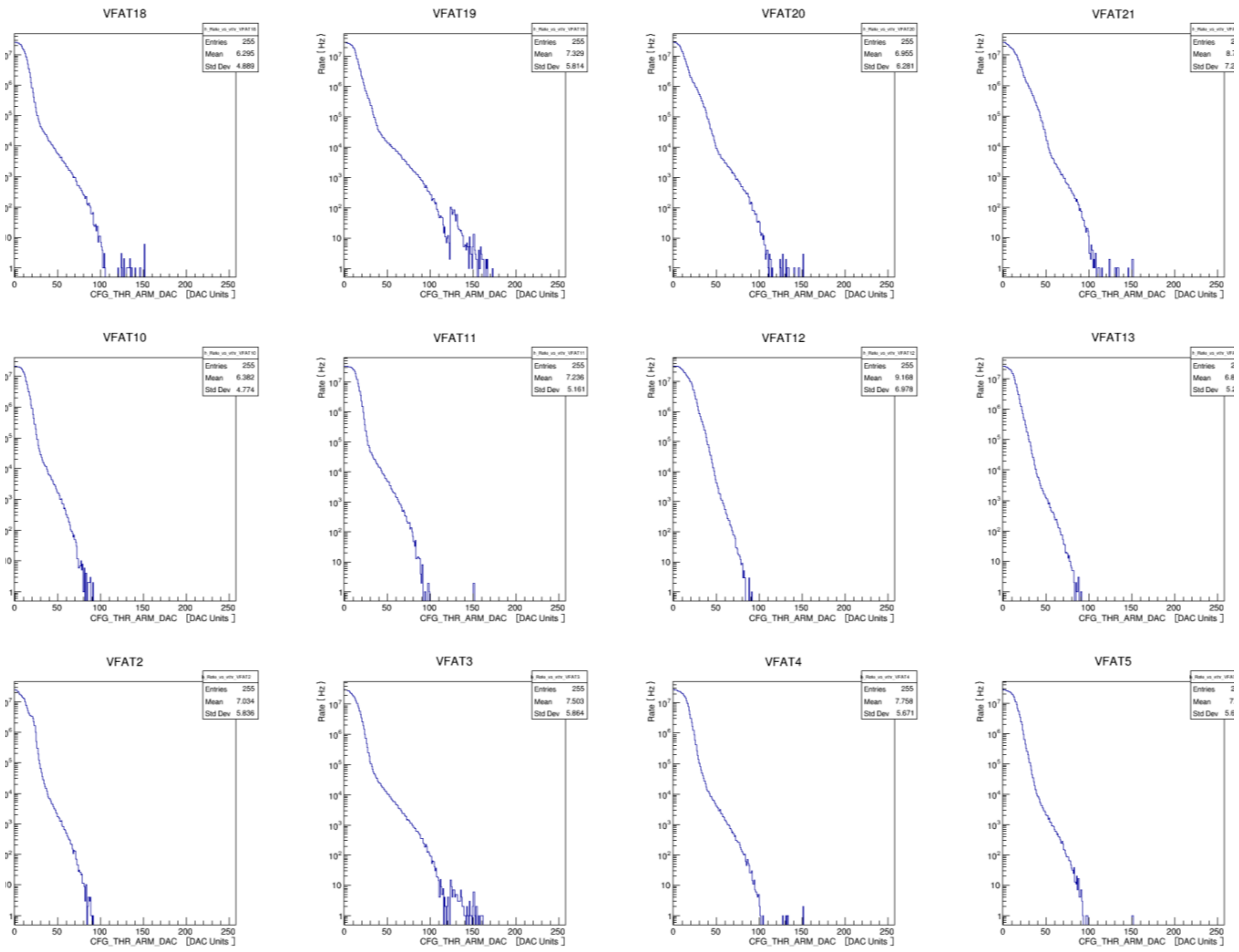
S-curve scan

- Send a calibration pulse to an individual channel and record whether a hit is register
- Vary the calibration pulse strength
- Provides a useful overview of the performance of the readout electronics
- Can be used to determine which channels are dead or which channels are hot and therefore should be masked
- Can also be used to characterize the noise
- x-axis: strip number
- y-axis: injected charge
- z-axis: number of hits out of 100



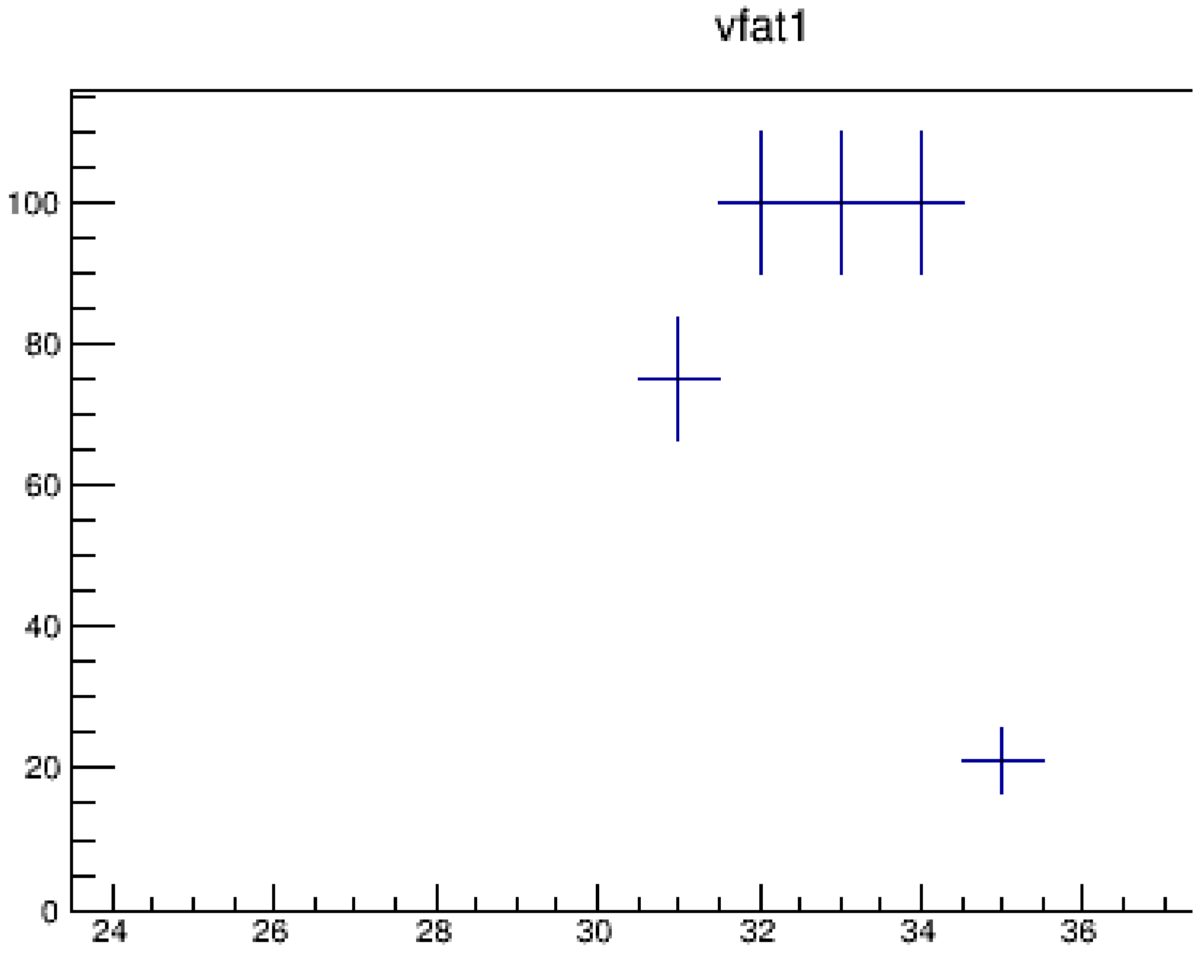
S-bit rate scans

- S-bit is a clustered data format for the trigger
- 14 bits: 11 bits for the cluster address and 3 bits for the cluster size
- Neighboring strips, up to 16, grouped together
- Plot shows rate as a function of global threshold register
- For this plot, the high voltage is off and the chamber is not filled with gas
- So, all of this is noise, and the threshold should be set in the tail of the distribution



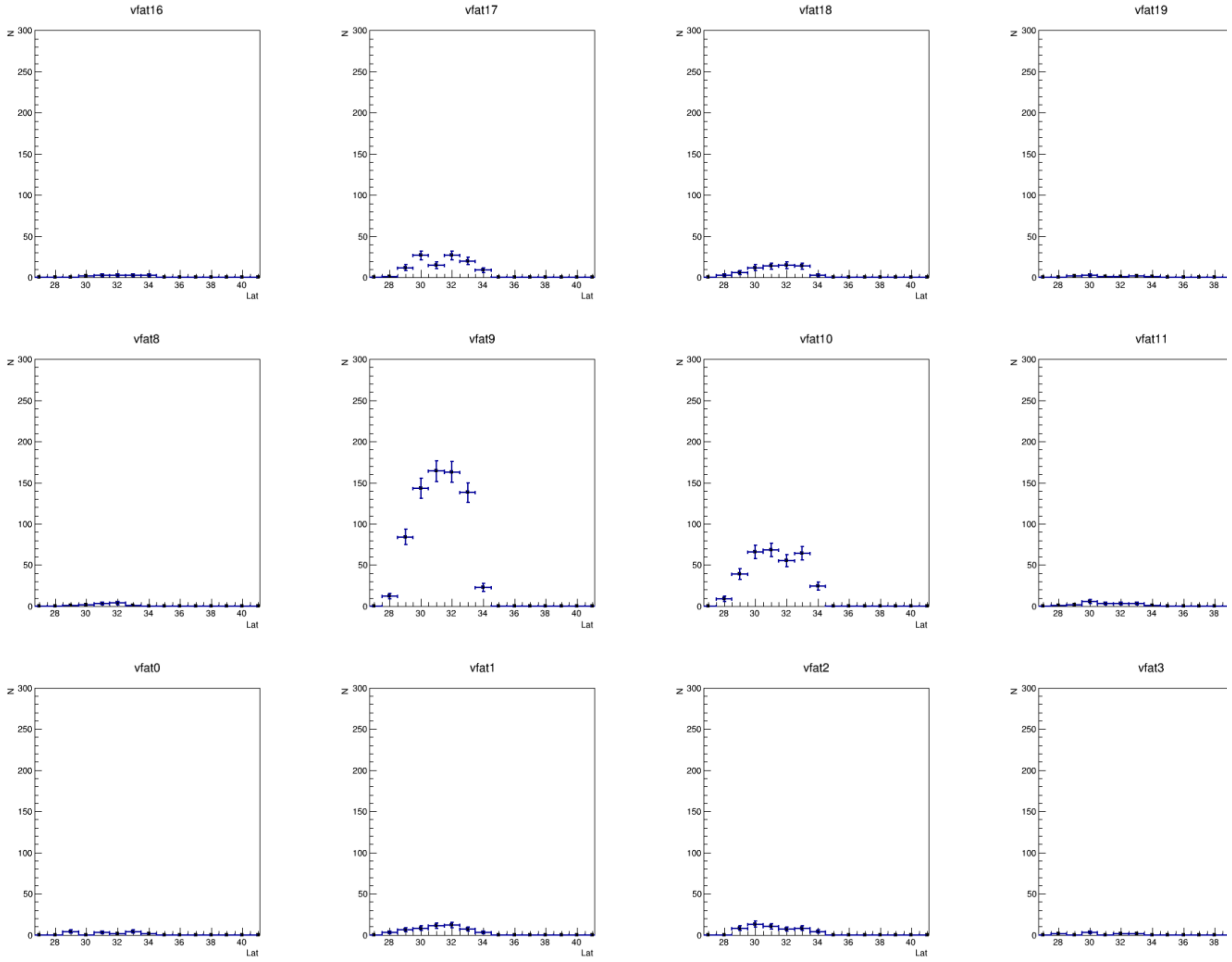
Internal latency scan

- Internal buffer in VFAT needs to know which time slot to fetch when it receives a level 1 trigger accept signal
- x-axis is latency in bunch crossings (25 ns)
- y-axis is the number of hits out of 100
- Pulse stretching factor of 4 applied, (would be set to 1 for collision data taking)



Latency scan

- Cosmic muon data taking (i.e. high voltage on and chamber filled with gas)
- Trigger taken from the coincidence of a pair of 10 cm by 10 cm PMTs above and below the detector and centered on VFAT9
- Again, pulse stretching factor of 4 applied
- Efficiency = sum of efficiencies in all of the VFATs for a fixed bunch crossing
- Efficiency lower than best achievable due to non-optimal high voltage settings



Conclusion

- The CMS GE1/1, GE2/1 and ME0 upgrade projects are proceeding on schedule
- Thorough calibration and quality control procedures are critical
- Showed several types of calibration and quality control scans, which mainly test the front-end and back-end electronics
- Cosmic ray data taking, and the analysis of the cosmic ray data, is the next major step