Test of first endcap CMS GEM super-chambers at CERN

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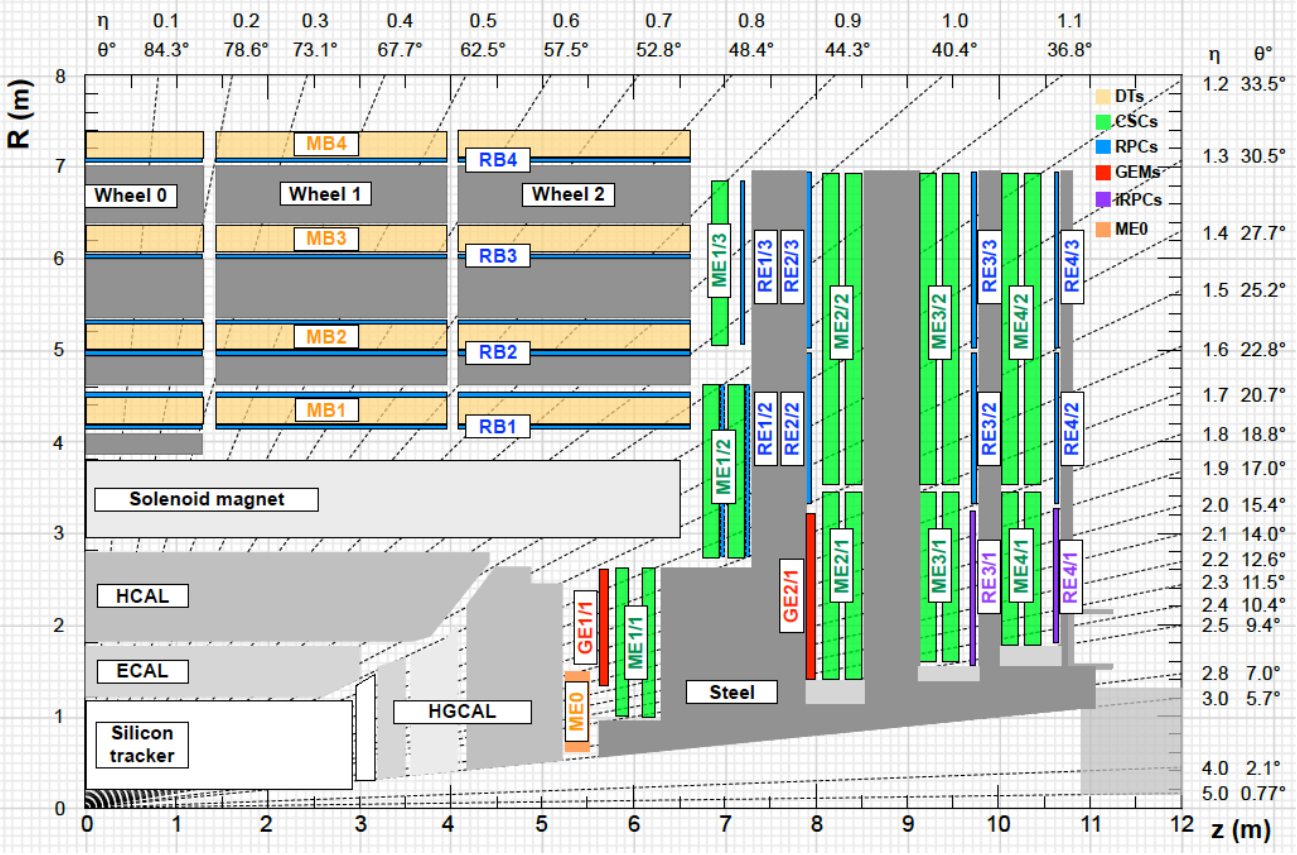
Introduction

- A triple-GEM detector uses 3 parallel GEM (gas electron multiplier) foils for successive avalanches
- GE1/1 is the innermost ring of the muon layer closest to the interaction point
- Installed on both positive and negative z
- 144 chambers will be installed
- Later will be installed in GE2/1 and ME0

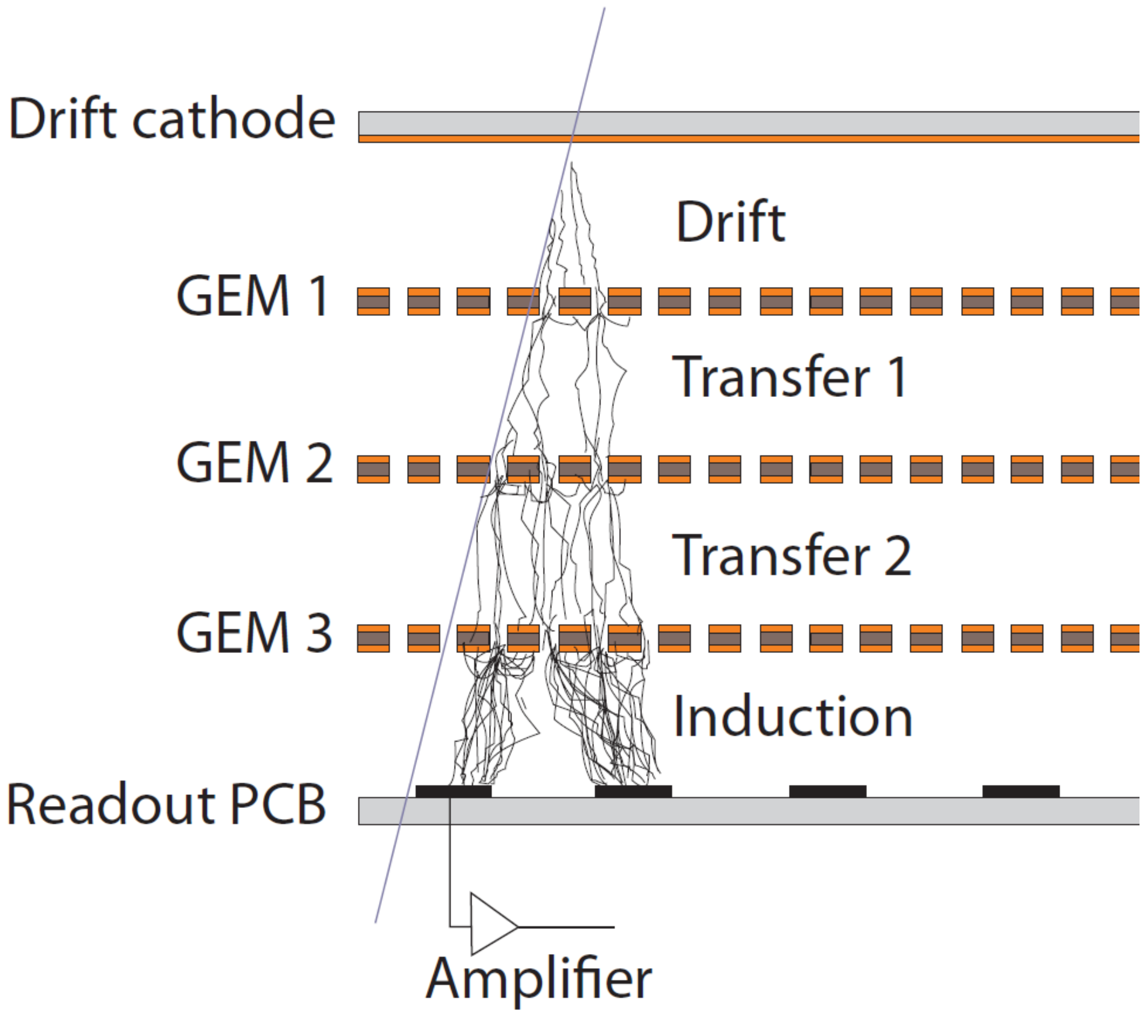


Outline

- Principles of operation
- Chamber design
- Calibration and quality control using cosmic ray stand (QC8)
    - DAC scan
    - GBT phase scan
    - Per-channel threshold scan
    - Global threshold scan
    - Efficiency calculations
    - Efficiency measurements
    - Alignment
- Installation in the CMS detector
- Detector Control System (DCS)
- Data Quality Monitoring (DQM) system
- Conclusion

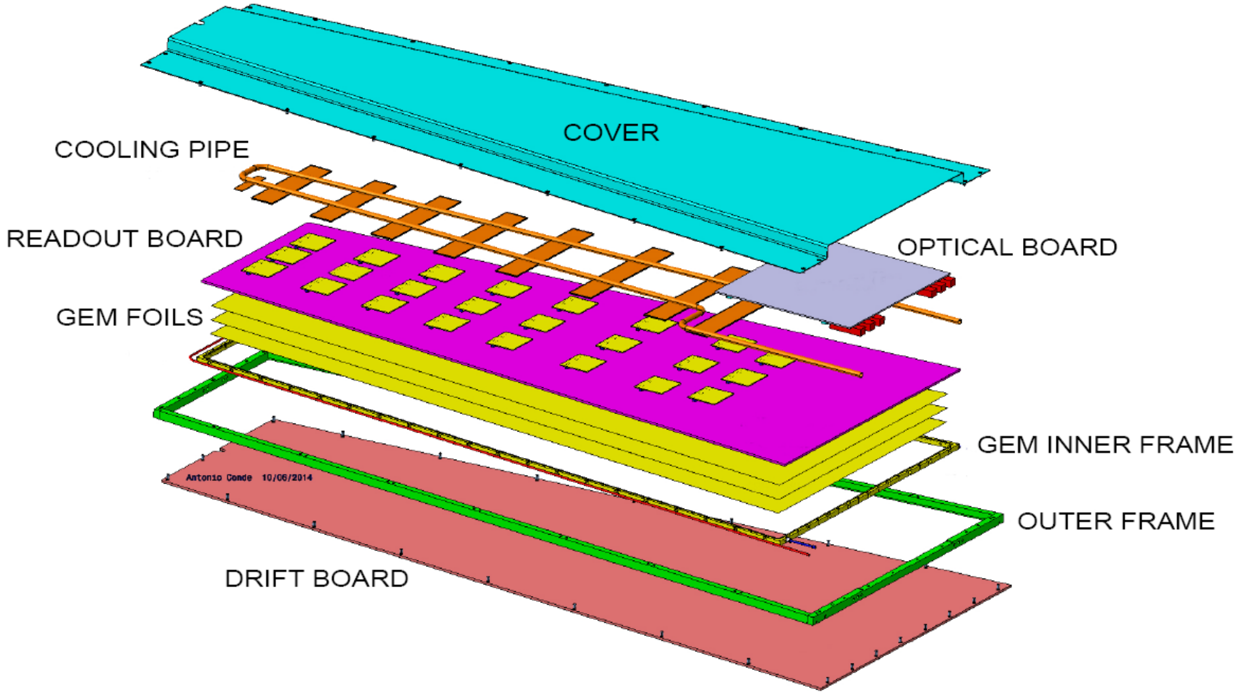
Principle of operation

- 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



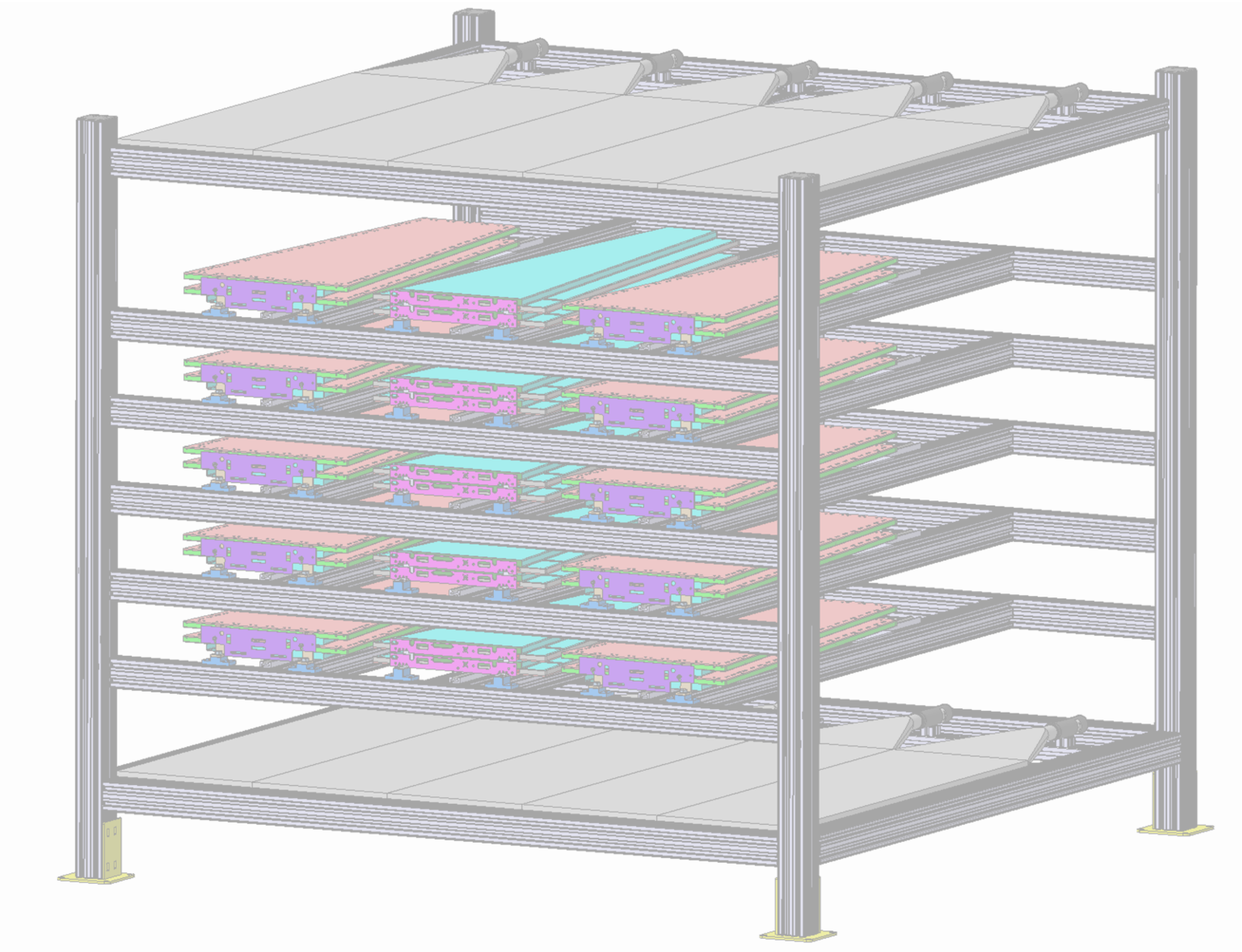
Chamber design

- 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
- Each VFAT contains 128 channels corresponding to 128 strips
- Two chambers are combined to form a super-chamber
- Data is read out in optical links



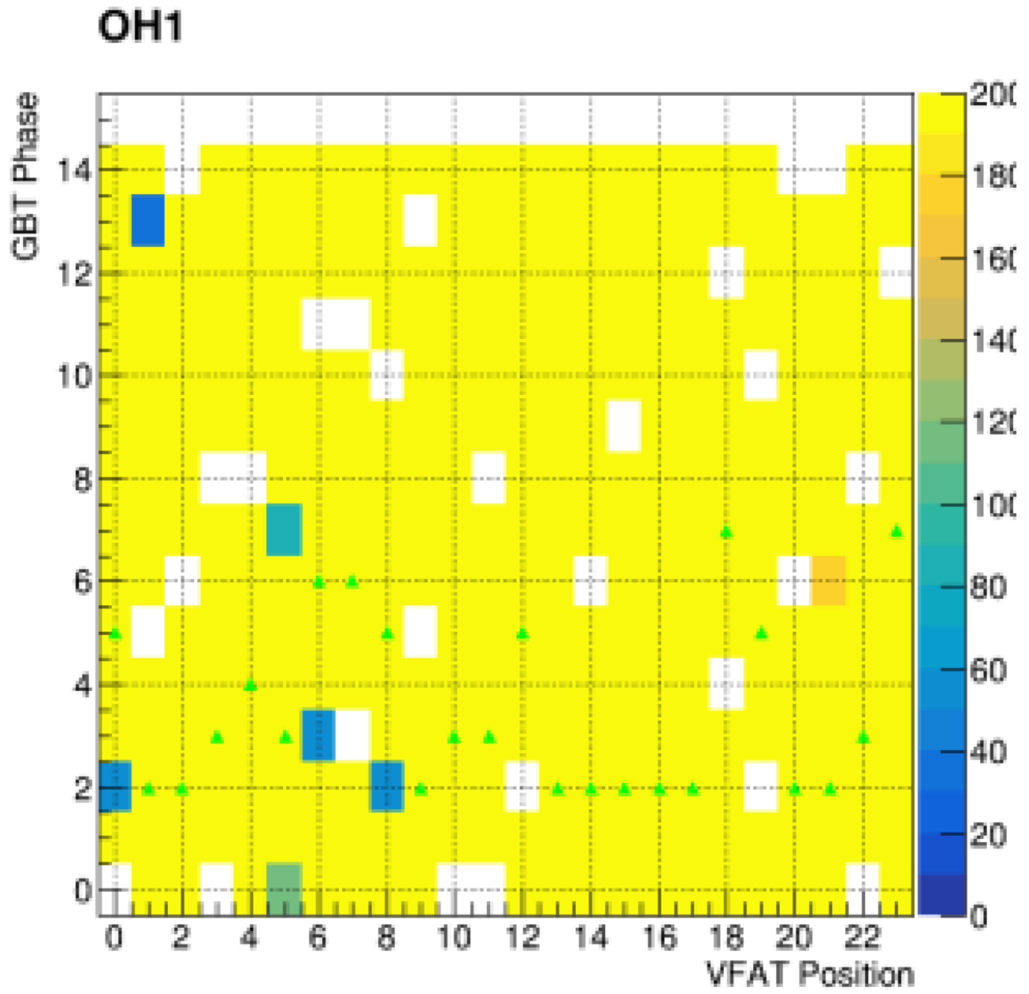
Cosmic ray stand testing (QC8)

- Three vertical columns, one back-end board (AMC) per column
- Each column contains five super-chamber slots
- Five PMTs above and below for triggering
- Trigger rate (coincidence between upper and lower PMTs) is around 90 Hz
- The flux of muons is proportional to cos^2(theta), where theta = 0 is normal
- Used to perform calibration and quality control, and measure efficiencies



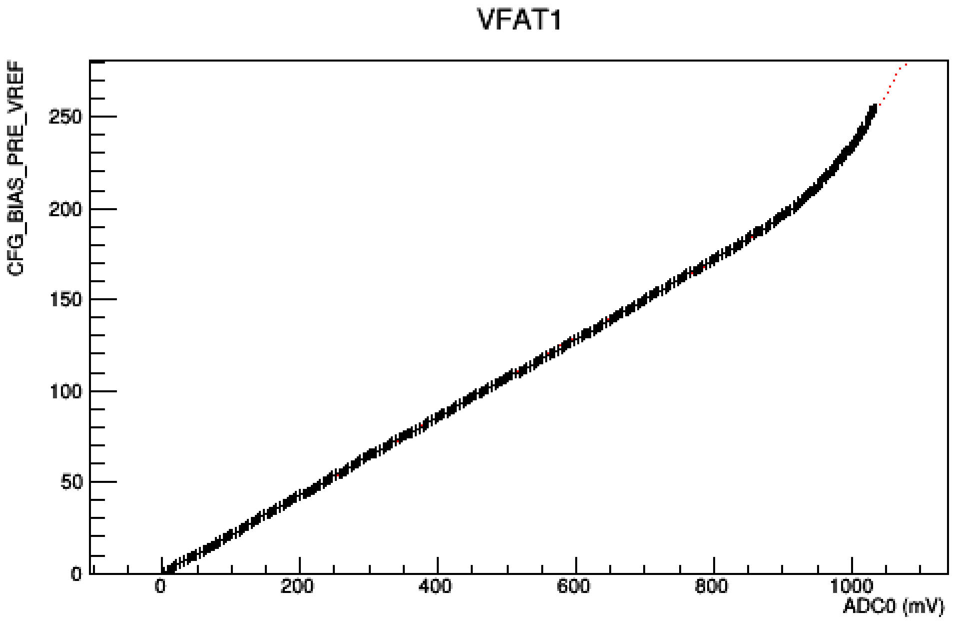
GBT phase scans

- Phase delays in the optical links depend on the cable lengths and several other factors
- The optical link receivers should set the sampling intervals to be consistent with the phase delay
- For the figure on the right:
    - x-axis: VFAT number
    - y-axis: GBT phase
    - z-axis: number of successes (four critical registers on the VFAT can be read)
- VFATs that fail for every GBT phase are replaced
- Criteria for passing QC8: at least one good GBT phase per VFAT



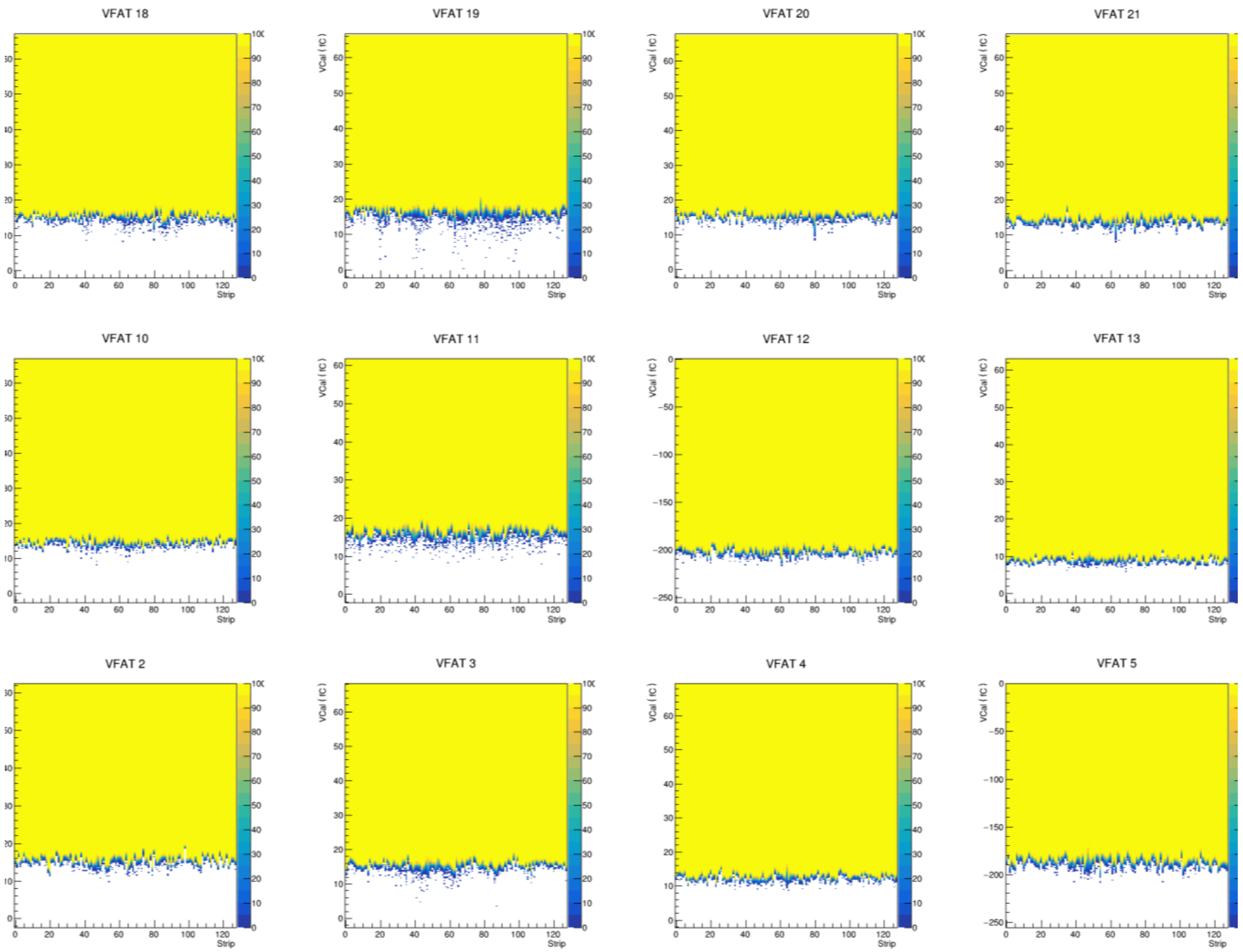
VFAT bias (DAC) scans

- 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
- Criteria for passing QC8: nominal value is within



S-curve scans

- Send a calibration pulse to an individual channel and record whether a hit is register
- Vary the calibration pulse strength
- x-axis: strip number
- y-axis: injected charge
- z-axis: number of hits out of 100
- Criteria for passing QC8 is that no more than 3 channels are dead or hot per η sector



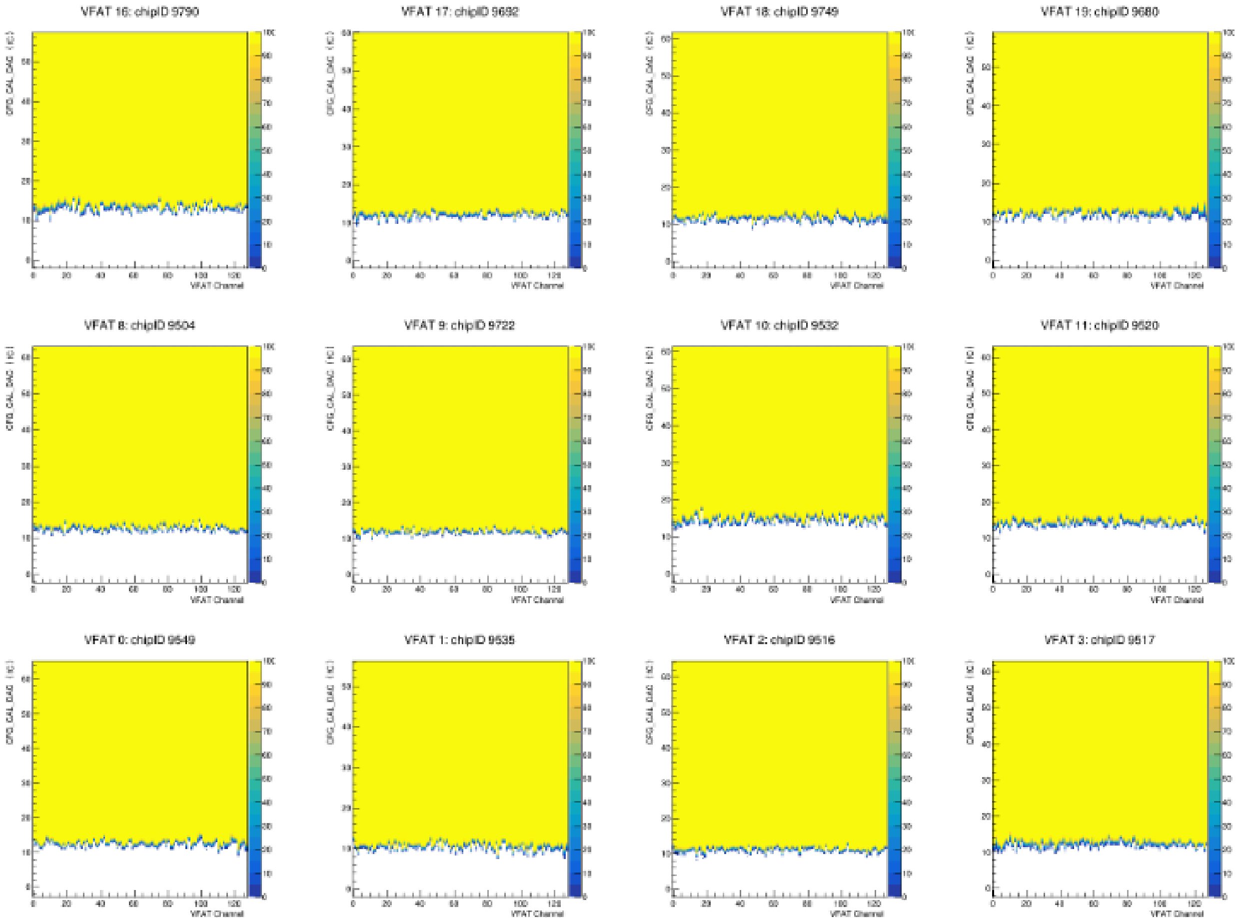
Iterative per-channel calibration algorithm (trimming)

1. Perform S-curve scans and fit the threshold (μ_c) and noise level (σ_c) for each channel
2. Calculate the mean value of the measured thresholds (μ_m)
3. For each channel apply the following formula: $v_T = (\mu_m - \mu_c + 4 * \sigma_c) * 15\ (mV/fC) / 1\ mV$
4. Round the v_T to an integer value to get a setting for the per-channel threshold
5. Apply the updated per-channel thresholds
6. Go back to step 1.

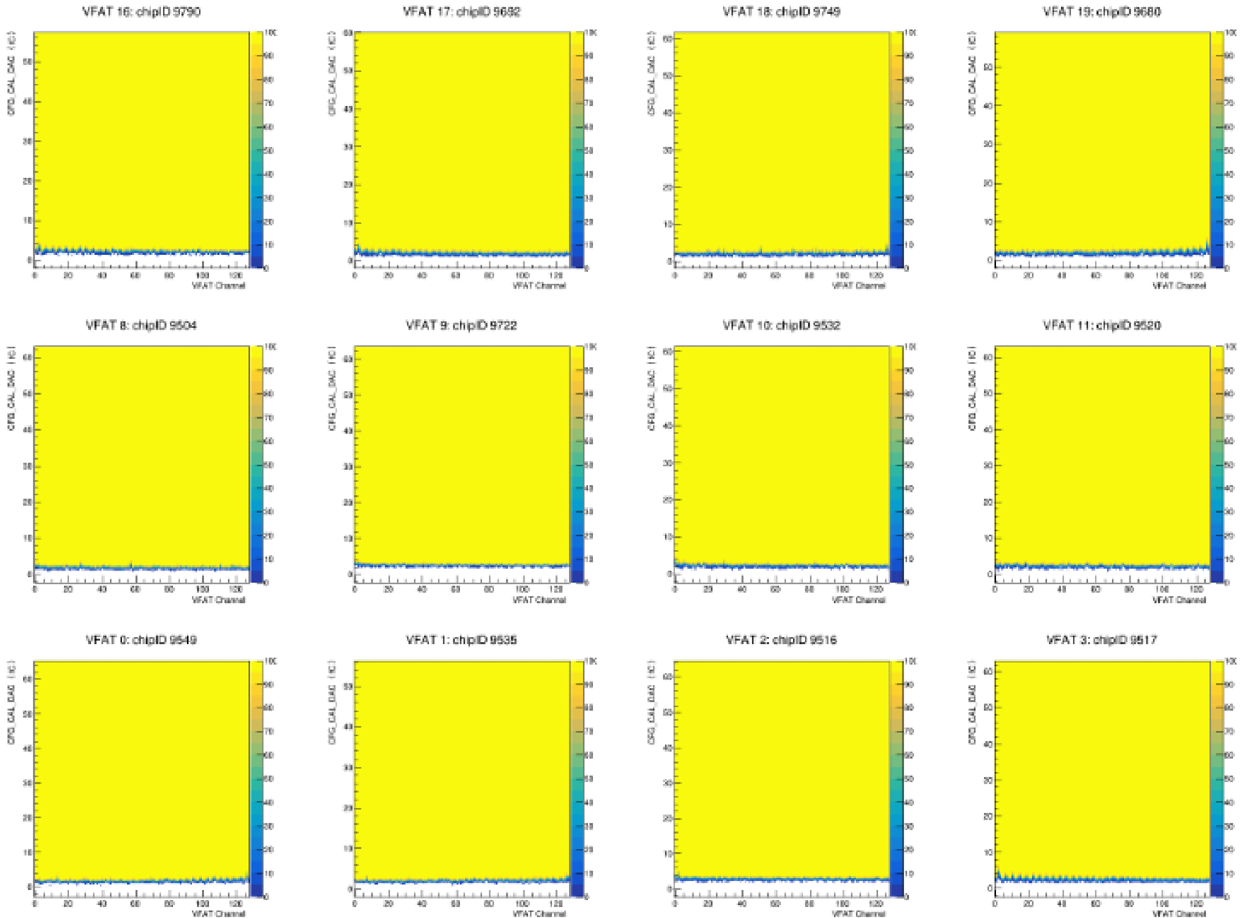
- 15 mV/fC is the channel expected medium gain and 1 mV is the LSB value of the
- $+4*\sigma_c$ is used to align the channel mean plus an offset instead of the mean, such that outlier channels with large noise do not spoil the overall noise level

Trimming results

Untrimmed

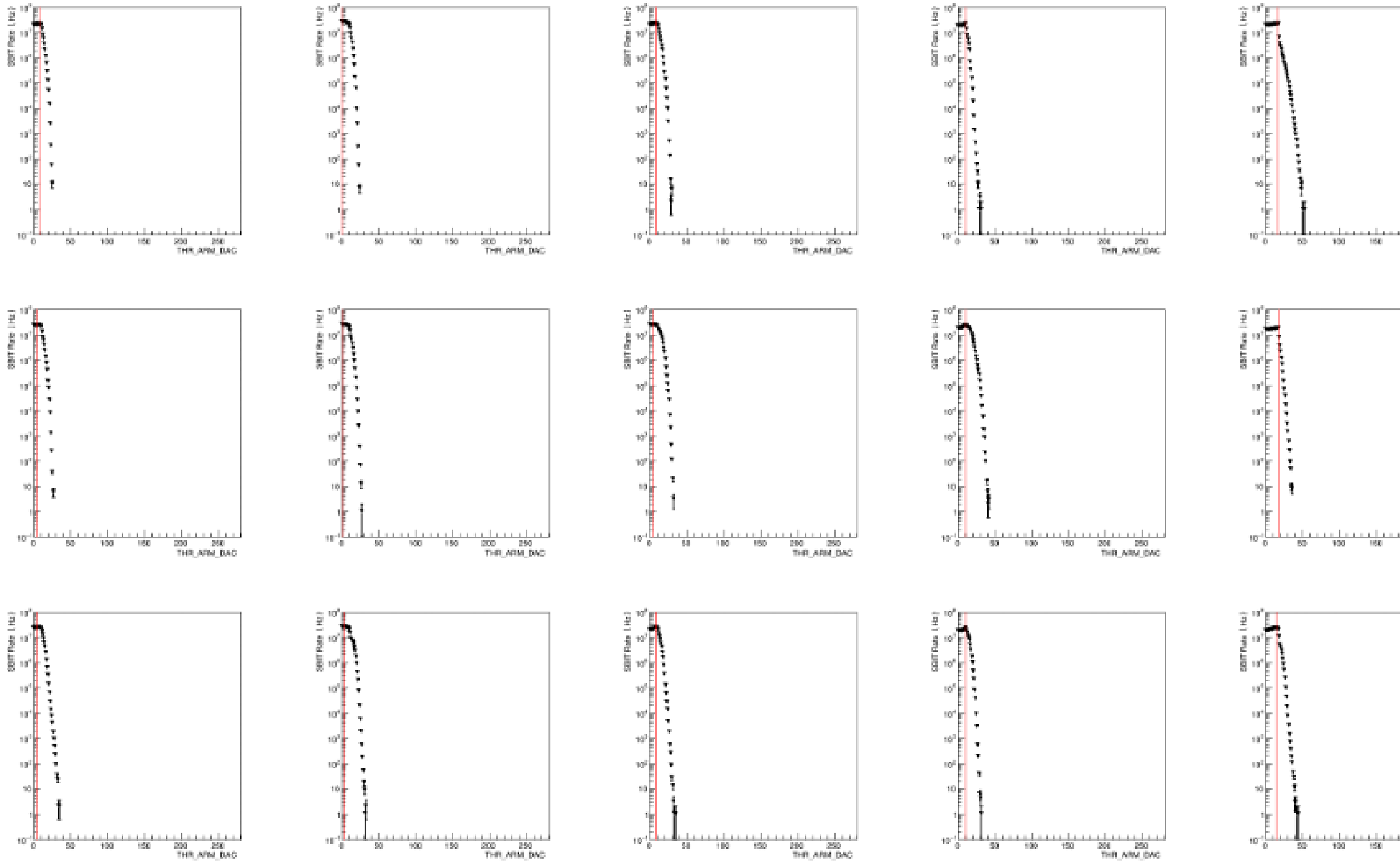


Trimmed



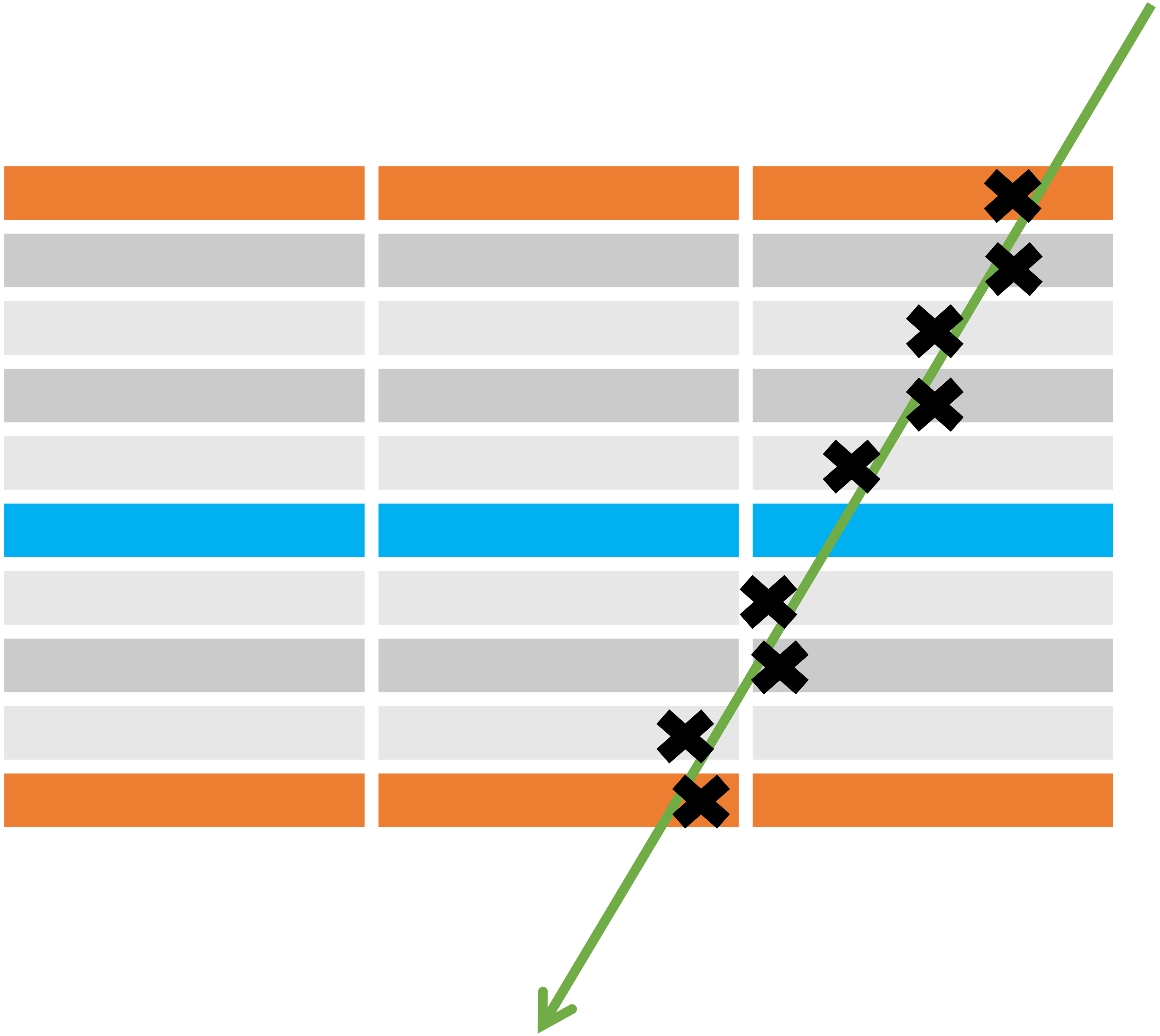
Global threshold calibration

- Plot shows the per-VFAT hit rate as a function of global threshold register with the high voltage turned off i.e. only noise
- Iterative procedure developed to align channel response, which allows us to then decrease the global threshold and therefore increase the efficiency at the same noise level
- Set global threshold corresponding to 100 Hz



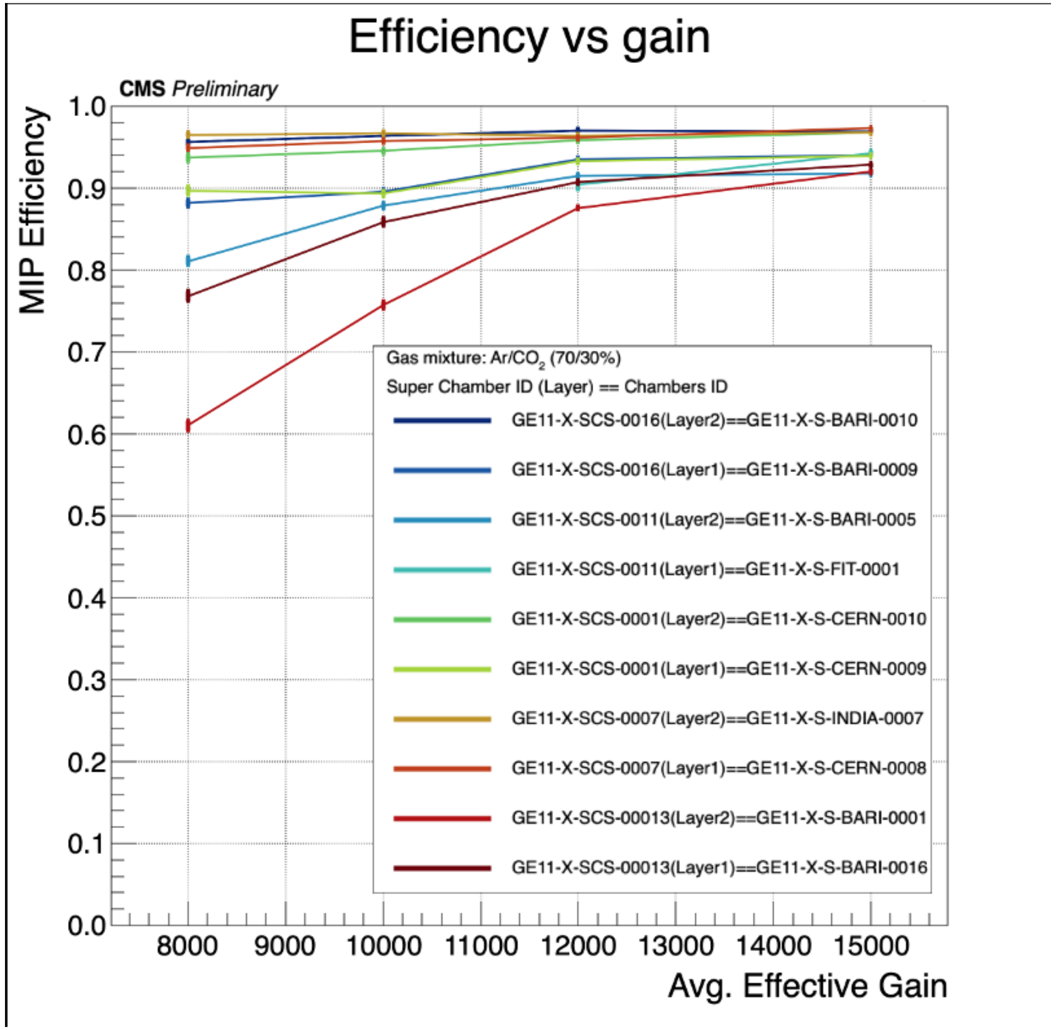
Efficiency calculation

1. One of the layers is selected for testing
2. One of the top two layers is used as the top seed and one of the bottom two layers is used as the bottom seed
3. Muon track is propagated from top seed to bottom seed (straight line)
4. Nearby hits on other layers are identified
5. Track is fit to collection of hits
6. Fitted track propagated to selected layer
7. Closest hit on the selected layer is identified
8. If x and y residuals are both < 5 sigma, the event is added to numerator and denominator, otherwise it is added to only the denominator



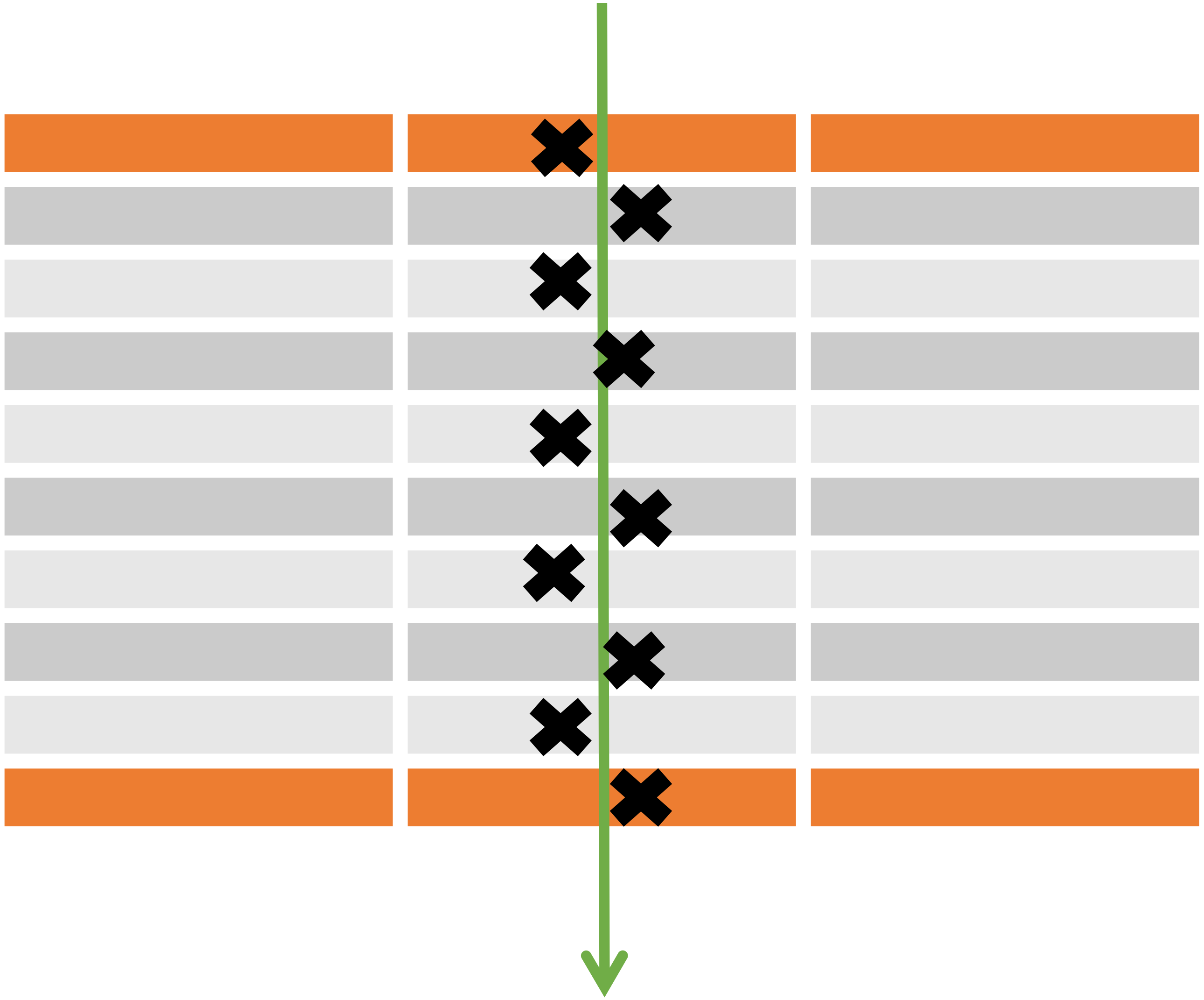
Efficiency measurements

- Measure detection efficiency as a function of effective gas gain
- Higher effective gas gain leads to more HV trips, so there is a tradeoff
- Criteria for passing QC8: efficiency of at least 90%
- We also calculate the efficiency per-VFAT and check for uniformity (if there is non-uniformity, we then try to compensate by with the other chamber in the super-chamber)



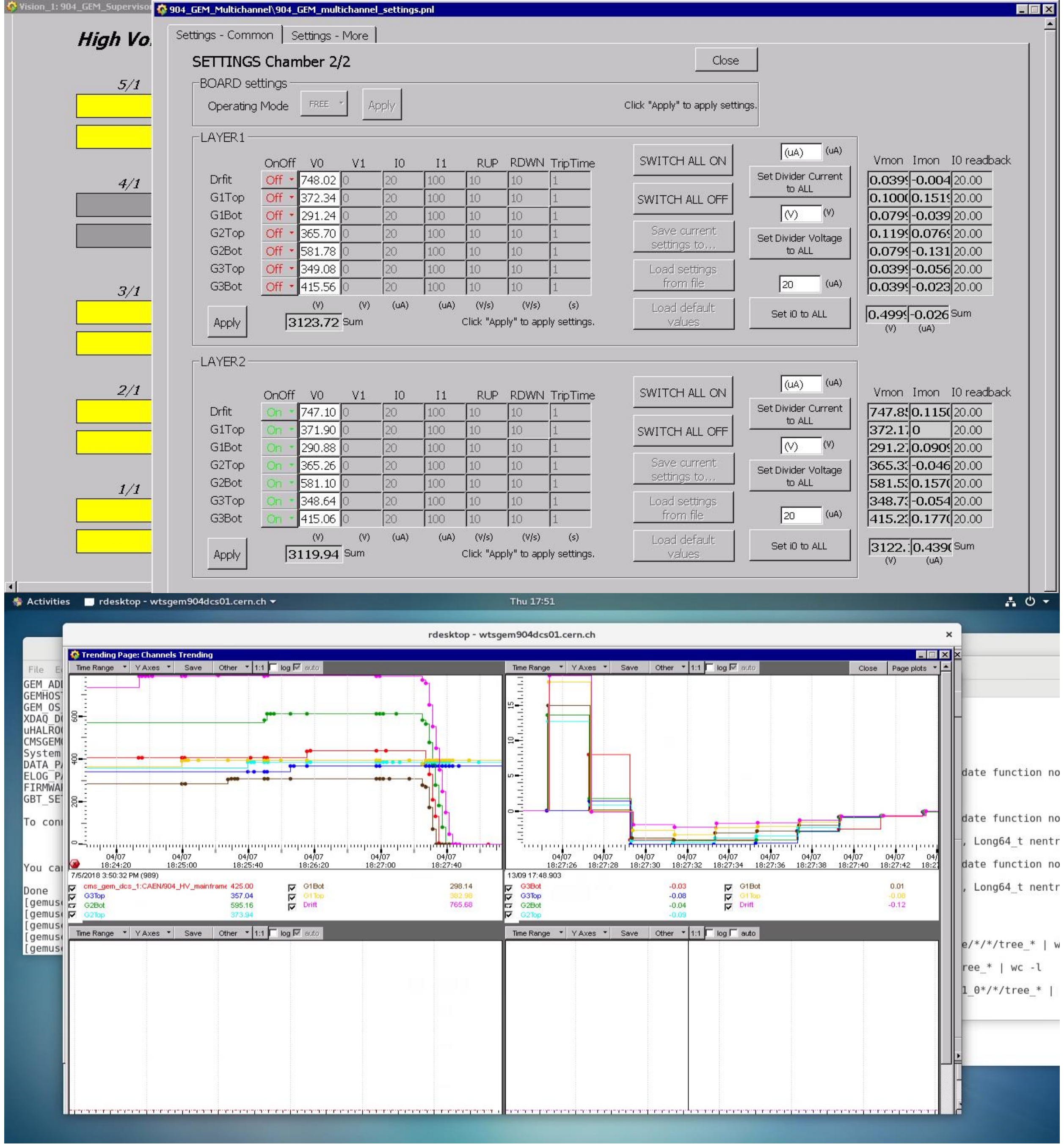
Alignment loop

1. Obtain **top** and **bottom** seeds as in the efficiency calculation, only allowing seeds within a single column
2. Nearby hits on other layers are identified
3. Calculate x residuals between fitted track and reconstructed hits
4. For each iη sector, calculate the centroid of the residual distribution
5. Fit a linear function to the centroid of the residual distribution as a function of iη
6. Translate and rotate chambers based on, and go back to step 2

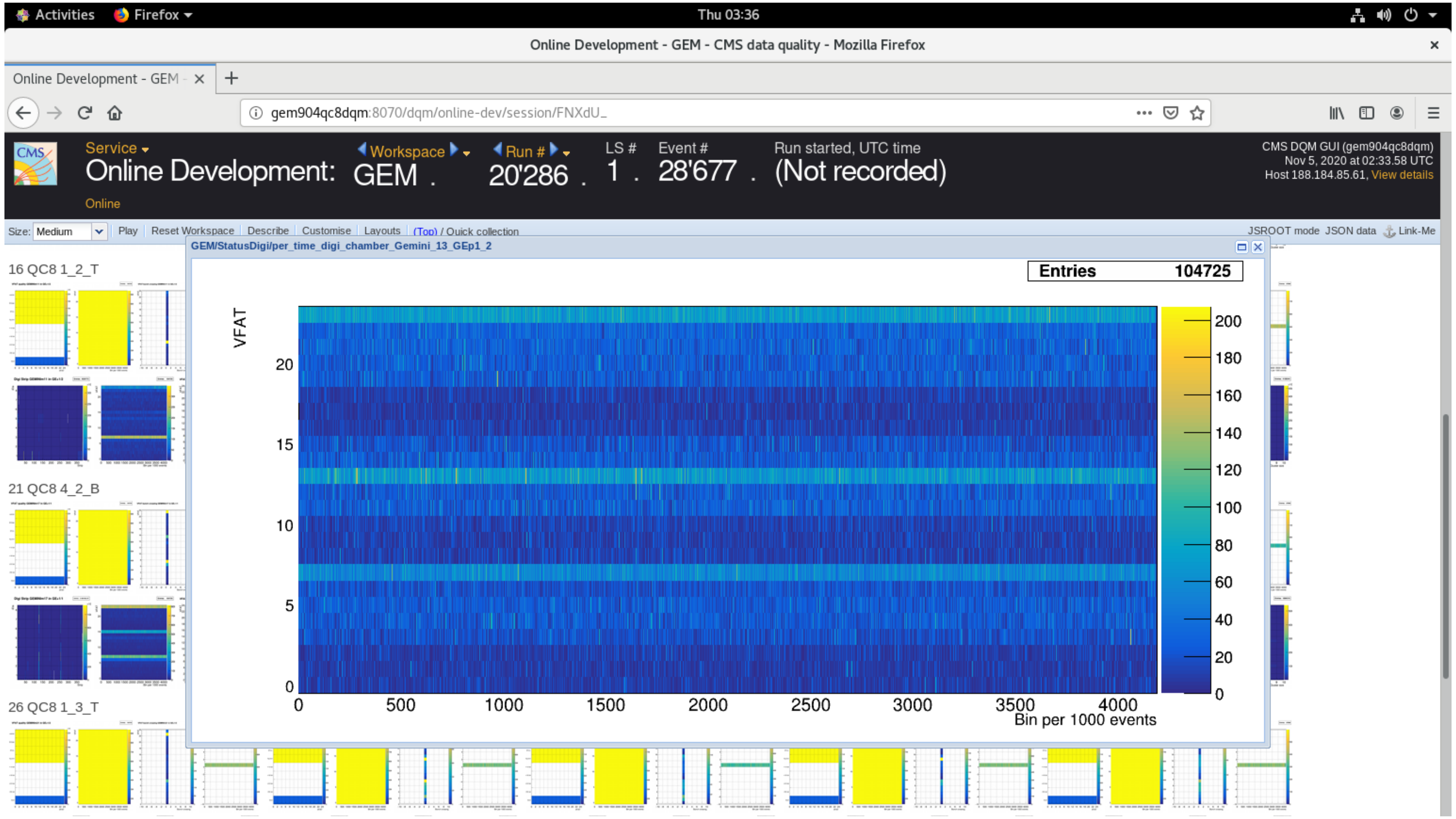


DCS (Detector Control System)

- User interface to control and monitor the voltages and currents on each layer
- Allows the user to set a maximum current and voltage to prevent damage to the detector during a trip
- Also allows the user to examine the history of the current and voltage measurements, for example in order to determine which layer caused a trip

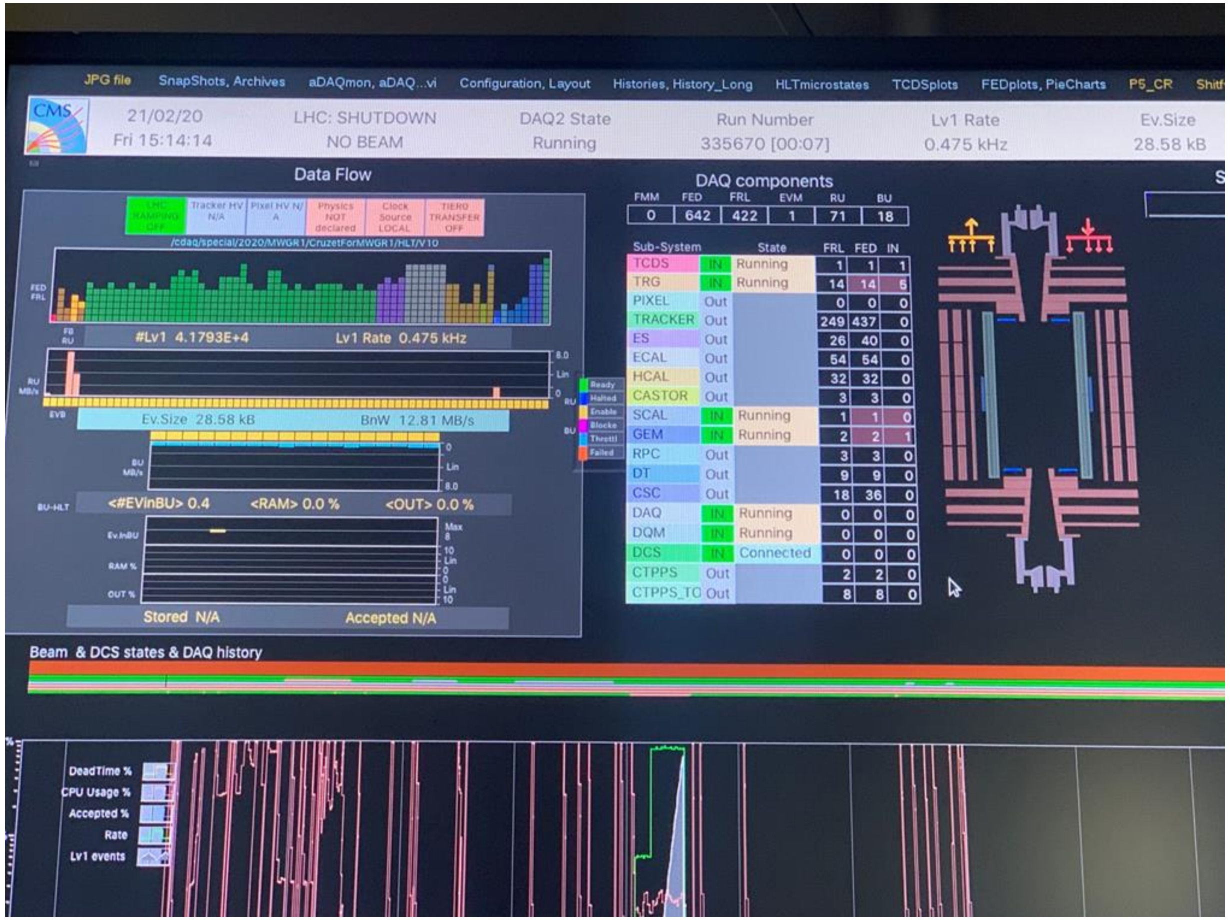


DQM (Data Quality Monitoring)



Installation and commissioning in CMS

GEM sub-system running in CMS global run



Conclusions

- 144 GEM chambers have been installed in the CMS endcap
- All 144 chambers + around a dozen spares were thoroughly tested with above-ground cosmic data-taking (QC8)
- QC8 procedure performs connectivity testing, biasing the VFATs, calibration, alignment, and efficiency measurements
- MIP efficiency typically ~95% for a single chamber
- Commissioning and integration is ongoing, and preparation for the next GEM upgrade project GE2/1