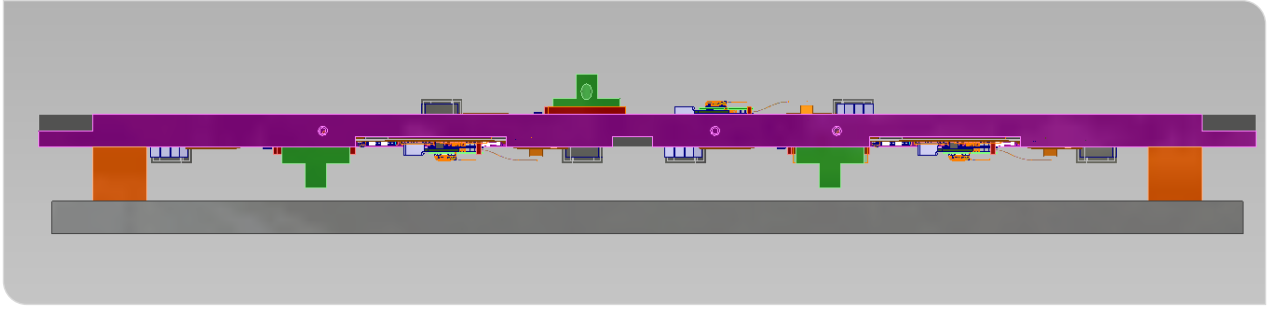
Laboratory and Integration Tests with 2S Module Prototypes for the Phase-2 Upgrade of the CMS Outer Tracker

Lea Stockmeier | February 14, 2022



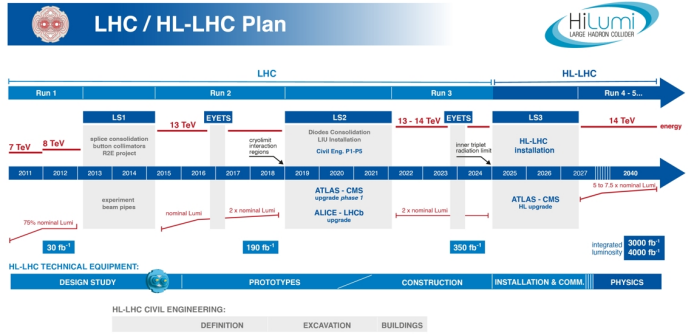
Outline

- The High-Luminosity LHC and the CMS Experiment
- The 2S Muon Hodoscope
- The Karlsruhe Ladder Mockup (KALAMO)
- Summary and Outlook

The High-Luminosity LHC and the CMS Experiment

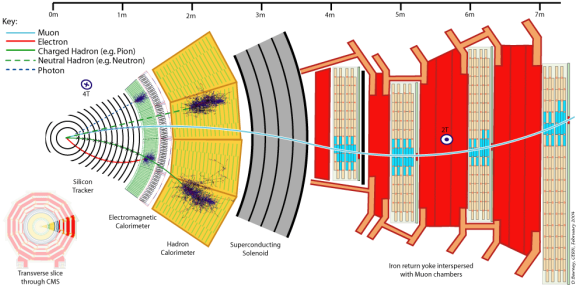
The High-Luminosity LHC Upgrade

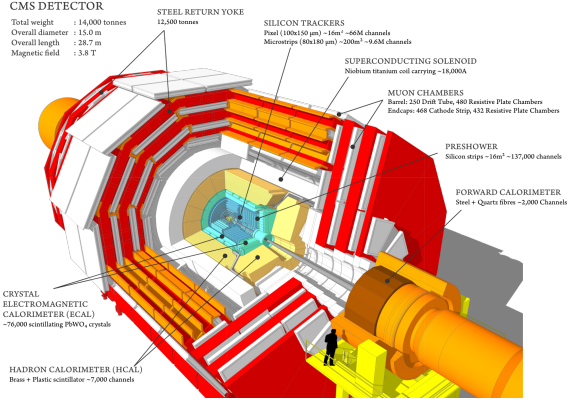
- Proton-proton collisions at $\sqrt{s} = 14$ TeV
- Upgrade idea
  - Enlarge statistics to search for new physics
  - Increase collision rate ($\sqrt{s}$ already at limit)
- **High-Luminosity LHC**
  - Increased luminosity
  - Up to 200 simultaneous interactions per bunch crossing
  - Begin of operation in 2027



The Compact Muon Solenoid Experiment

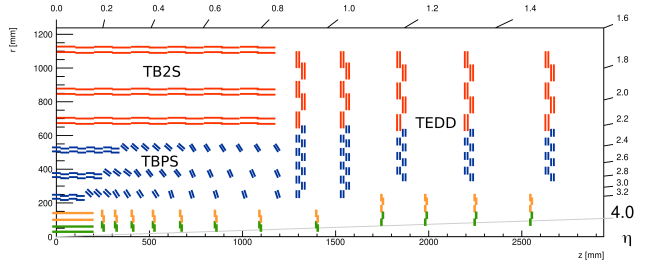
- Sub-detectors arranged in cylindrical layers around beam pipe
- Particle identification through combination of information from all sub-detectors

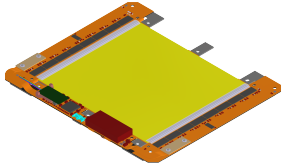




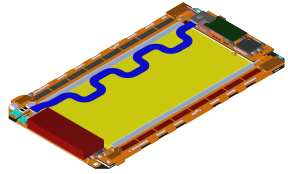
Phase-2 Upgrade of the CMS Outer Tracker

- Completely new CMS silicon tracker
  - Improved radiation tolerance
  - Increased granularity
  - Reduced material in tracking volume
- CMS Phase-2 Outer Tracker
  - $\approx$ 13 000 double-sided modules
    - 2S modules: strip-strip sensor
    - PS modules: pixel/strip sensor
  - Contribution to L1 trigger decision





2S module



PS module

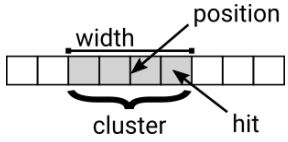
p_T Modules

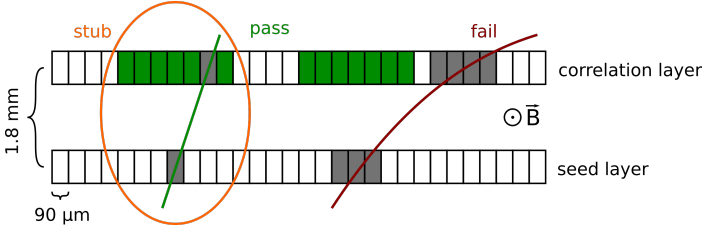
- Cluster: combination of neighboring strips with hits
  - Described by position (half strip precision) and width
- Stub: one cluster in each sensor within a predefined correlation window
  - Described by seed position and bend
- Bent trajectories of charged particles in magnetic field

  → High p_T particles produce stubs

  → Identification of particles with $p_T > 2\,\mathrm{GeV/c}$

  → Silicon tracker contributes to L1 trigger





2S Modules for the CMS Phase-2 Outer Tracker

Service Hybrid

Powering
Data transmission

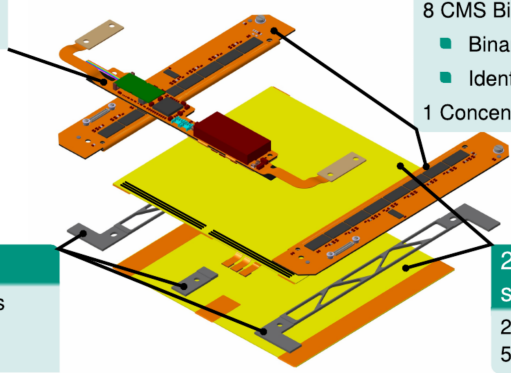
2 Front-end Hybrids

8 CMS Binary Chips[2] each

- Binary readout of sensor signals
- Identification of stubs

1 Concentrator Chip each

Binary readout: Hit recorded if signal is larger than threshold



Al-CF[1] Spacer

Spacing between sensors
Main cooling path
Mechanical fixation

2 parallel silicon strip sensors

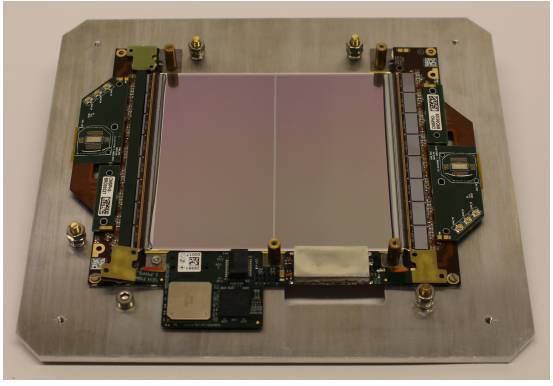
2×1016 strips each
5 cm length, 90 µm pitch

[1] Aluminum / carbon fiber composite

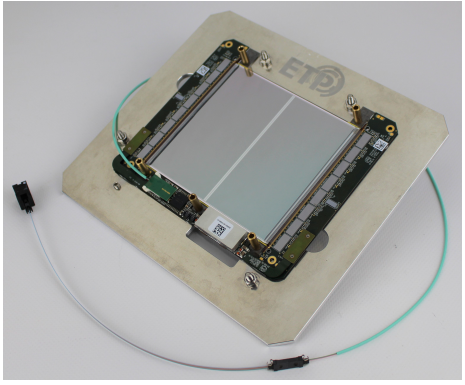
[2] Prydderch et al., *CBC3: a CMS microstrip readout ASIC with logic for track-trigger modules at HL-LHC*, CMS-CR-2017-383

Prototype Modules

- Before production start several prototype modules are assembled
- Prototypes of electronics → outer dimensions of modules differ
- Tests of module functionality in laboratory



8CBC3 prototype module

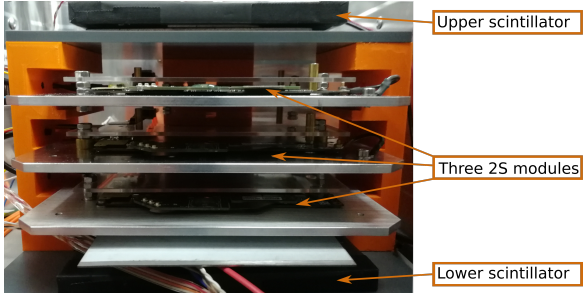


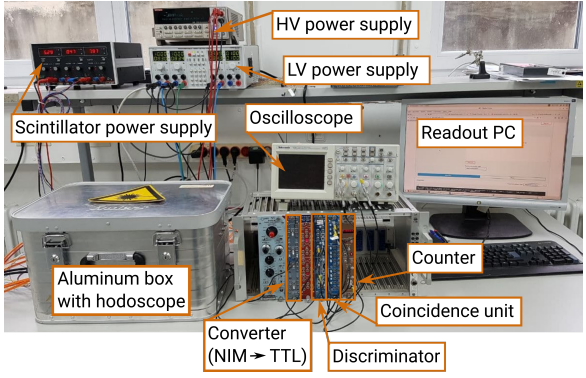
2S prototype module

The 2S Muon Hodoscope

Motivation and Experimental Setup

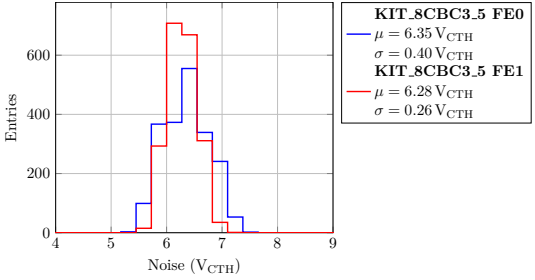
- Up to three 2S modules mountable
- Studies:
  - Synchrony of module readout
  - Muon signal charge reconstruction
  - Muon track reconstruction

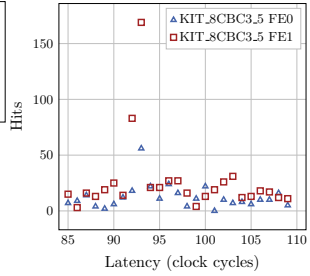


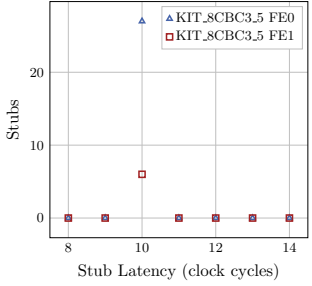


Single Module Measurements - Before Data Taking

- Noise scan: Gaussian distributed noise of each strip
- Latency scan: Time delay between signal and reading out the signal
  - Hits: 93 clock cycles
  - Stubs: 10 clock cycles

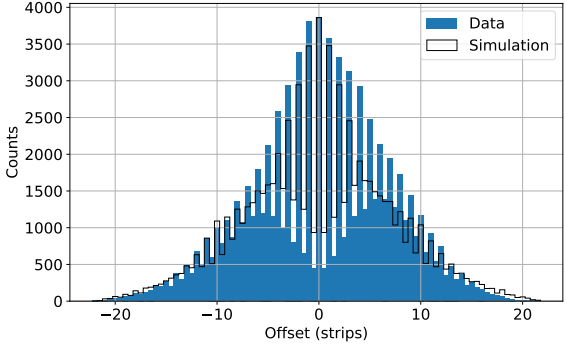


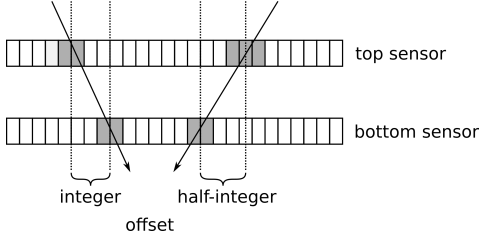




Single Module Measurements – Fixed Threshold

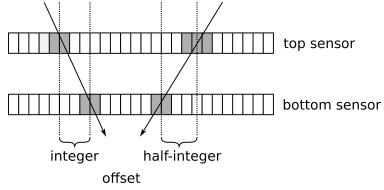
- 375,000 events at threshold of 555 V_{CTH} and −300 V bias voltage
- Correlated hits in both sensors → tracks from muons
- Integer and half-integer offsets in strips possible
- Same cluster size and thus integer offsets preferred

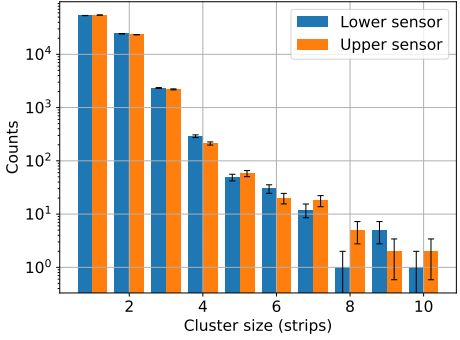


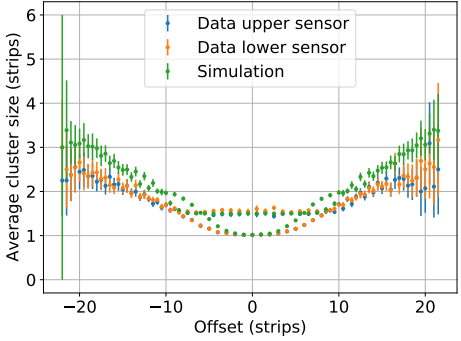


Single Module Measurements – Fixed Threshold

- Cluster size distributed equally in both sensors
- Average cluster size increases with offset in strips
  - Integer offsets: Minimum at 1 (1 hit per cluster)
  - Half-integer offsets: Minimum at 1.5 (1 and 2 hits per cluster)

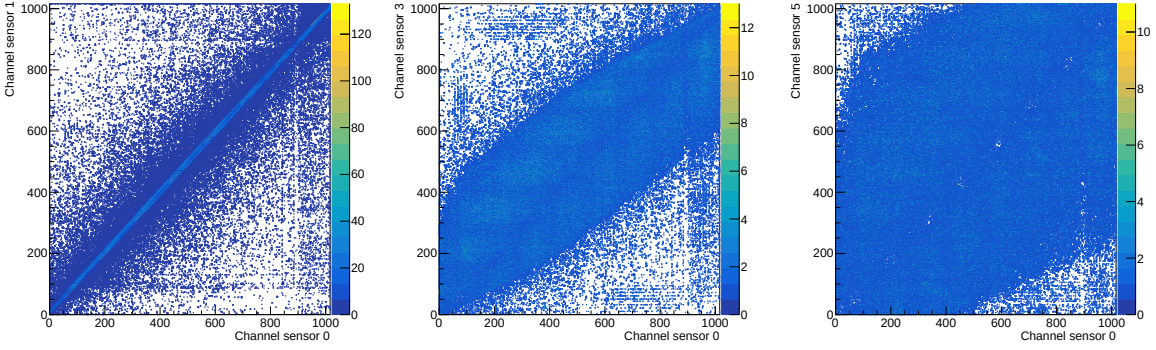






Measurements with Three Modules - Fixed Threshold

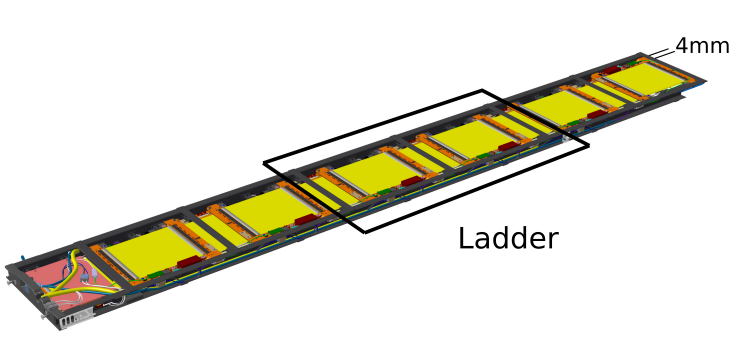
- 945 000 events at threshold of 555 V_{CTH} and −300 V bias voltage
- Selection criteria: At least one hit per sensor and fewer than 11 hits per sensor
- Hits in sensors correlated → tracks from muons

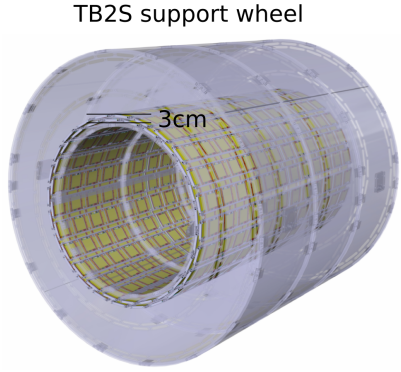


The Karlsruhe Ladder Mockup (KALAMO)

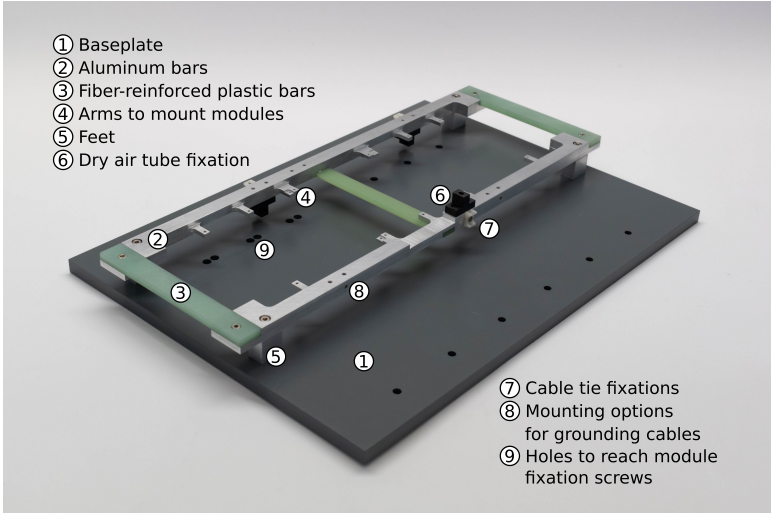
Idea

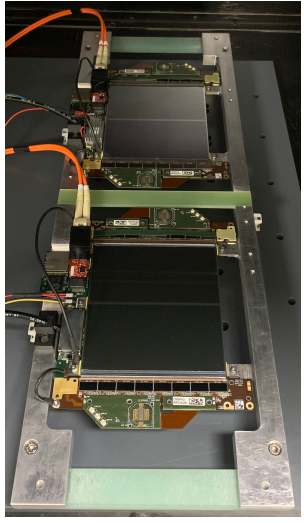
- In upgraded CMS detector: 2S modules operated at close distances
- Karlsruhe Ladder Mockup (KALAMO)
  - Test influence of module electronics in operation on neighboring modules
  - Preparation for integration tests
  - 8CBC3 and 2S prototype modules



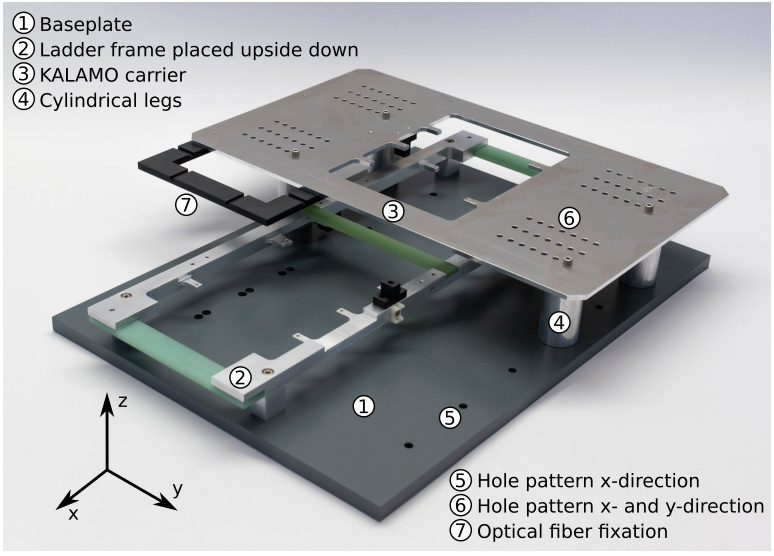


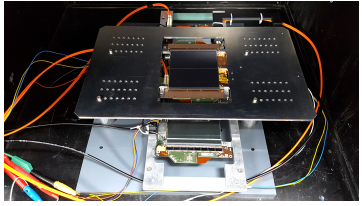
Ladder Configuration





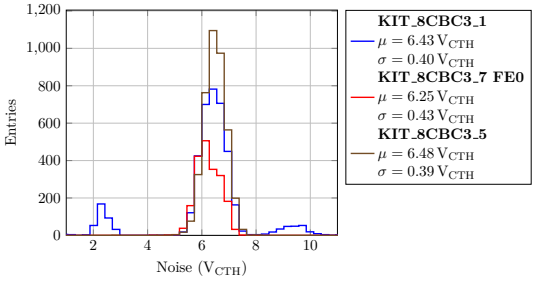
Barrel Configuration

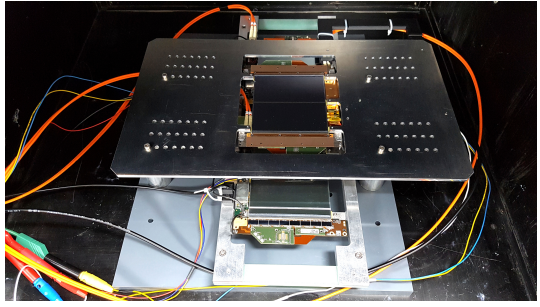




Noise Measurement

- Three modules installed
- Same noise level of modules as mounted on their carriers
- Room temperature
- $U_{\text{bias}} = -300\,\text{V}$

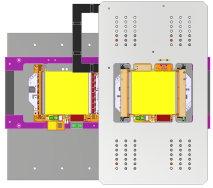


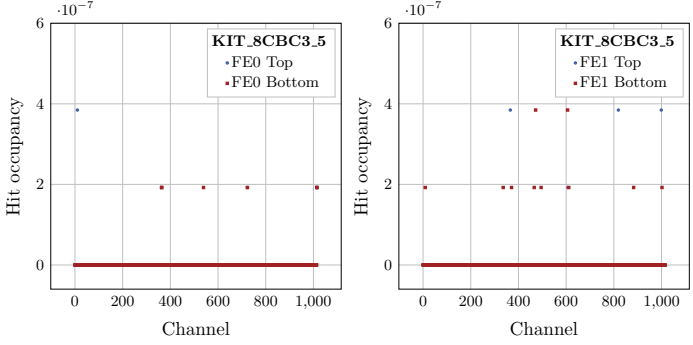


Test Pulse Injection

- Trigger three modules with the same trigger source (internal test pulses)
- Inject test pulses in two of three modules
- Measure hit occupancy in third module
  Hit occupancy = $\frac{\#\text{ of hits}}{\#\text{ of triggers}}$

  → Relocate upper module to probe potential disturbances by excess in hit occupancy

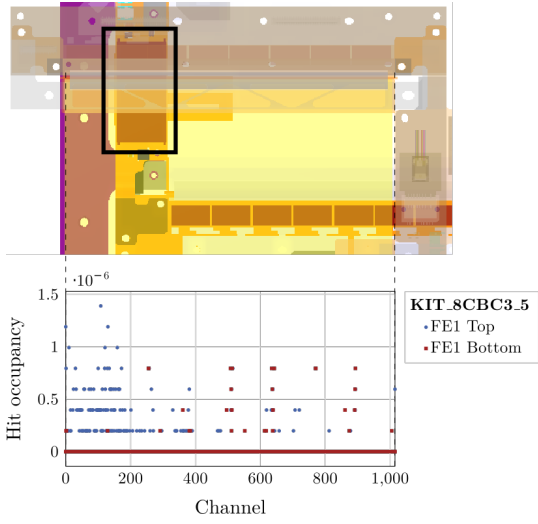




Position Scan

- Excess in hit occupancy of FE1 top occurred at some positions
- Module placed upside-down: top sensor nearer to lower modules
- Independent of test pulse injection
- Moving when changing position of upper module
- Could originate from aluminum bar or DC-DC converter

  → Further investigation with 2S prototype modules



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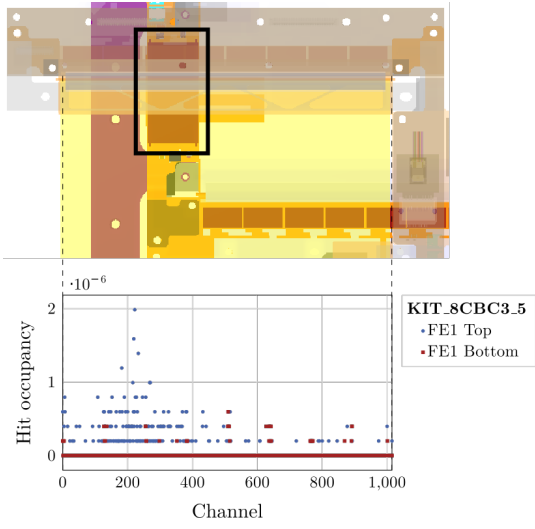

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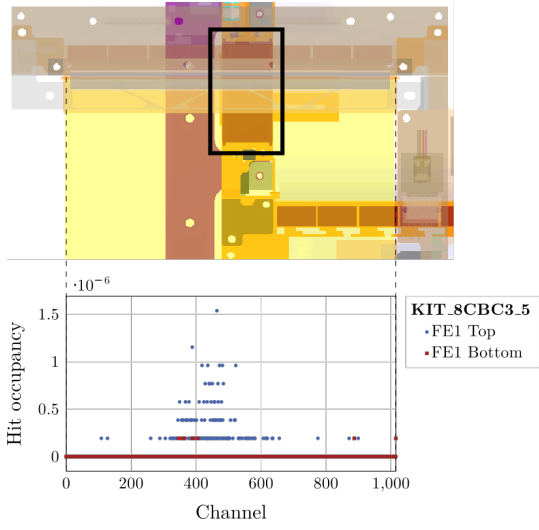


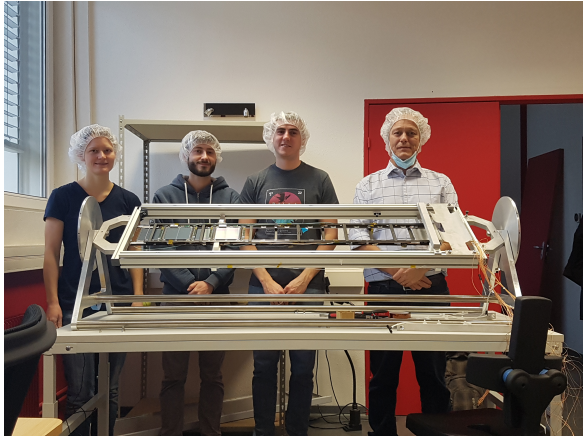
Position Scan

- Large rectangle: dimensions of FE1 upper module
- Small rectangle: DC-DC converter shield is closest to upper module sensor

  → Further investigation with 2S prototype modules

Summary and Outlook

- General idea: Test 2S modules and systems of 2S modules in the laboratory
- 2S muon hodoscope
  - Correlation of hits in different sensors
  - Tracks from muons
  - Synchronous module readout
- Karlsruhe Ladder Mockup (KALAMO)
  - Investigating grounding and disturbances with several modules at close distance
  - Measurements with prototype modules performed
  - Work leading to presented results showed that measurements are very sensitive to “good” grounding connection
- Continue with laboratory and integration tests during PhD

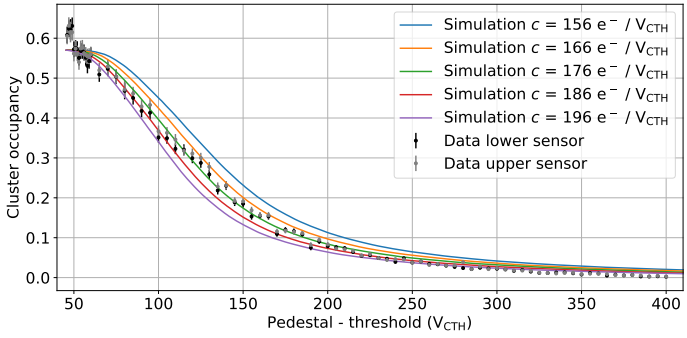


Karlsruhe Institute of Technology

Backup

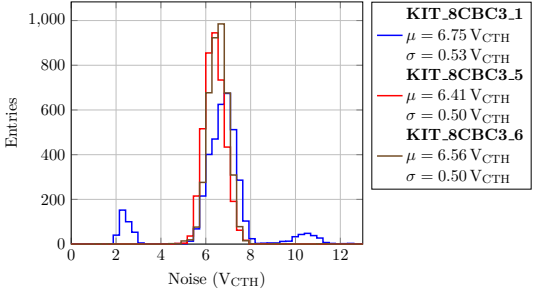
Single Module Measurements - Threshold Scan

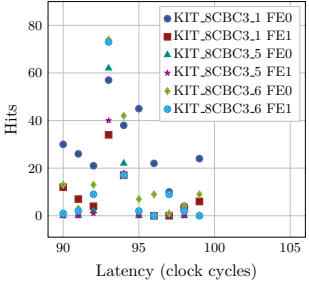
- Unit of internal DAC values: V_{CTH}
- Varied threshold from 200 V_{CTH} to 575 V_{CTH} with -300 V bias voltage
- recorded 10 000 to 20 000 events per threshold
- Data from three most efficient TDC bins
- Integrated simulated seed charge compared with measured cluster occupancy
  Cluster occupancy $= \frac{\#\text{ of clusters}}{\#\text{ of triggers}}$
- Conversion factor $c = 176\,e^-/V_{CTH}$ fits best

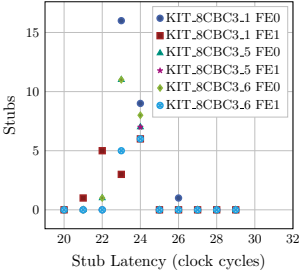


Measurements with Three Modules - Before Data Taking

- Noise scan: Gaussian distributed noise of each strip
- Latency scan: Time delay between signal and reading out the signal
  - Hits: 93 clock cycles
  - Stubs: 24 clock cycles







Measurements with Three Modules - Fixed Threshold

- Alignment for the sensors of the middle module
- Tracking via linear fit to all cluster combinations
- Dip in angular distribution: linked with bright spots in correlation plots?