Today:

- Tile Calorimeter overview
- Calibration systems
- Maintenance at the pit
- Test Beam for upgrade candidates
The Tile Calorimeter

● A hadronic calorimeter in the ATLAS detector that includes:
  ○ One central barrel and two extended barrels
  ○ 256 drawers total in the barrels
  ○ In each drawer, a slot for 48 PMTs (45 used in long barrel, 36 in extended)
  ○ A total of about 10,000 PMT’s (about 20,000 Analog-to-Digital Converters)

● Plastic scintillator tiles sample the energy within the detector
● Optical fibers transmit the light to PMT cells located inside Drawers
Tile Calorimeter Calibration

- 3 main calibration systems: Cesium, Laser, and Charge Injection System (CIS)

\[ E_{\text{channel}} \, [\text{GeV}] = A \, [\text{ADC}] \cdot C_{\text{ADC}\rightarrow\text{pC}} \cdot C_{\text{pC}\rightarrow\text{GeV}} \cdot \epsilon_{\text{Cs}} \cdot \epsilon_{\text{Laser}} \]

- Each system tests a specific element of the readout chain
Cesium

- Uses (~10mCi) sources of Cesium-137 to test the stability and uniformity of the optical response of every scintillator tile
- While the source drifts through calibration tubes by flow of liquid, integrated PMT currents are read out
Laser

- Sends laser pulses of known intensities into the photocathodes of PMTs and collects data in low gain the absence of collisions
- An infrared laser emits a 532 nm green light beam at a few microJoules maximum energy, which is sufficient to saturate channels and test their dynamic range
- The pulse shape is ~10ns, which is similar to the shape of physics signals
- Laser intensity experiences ~5% variation, so the system includes photodiodes to precisely measure the intensity of each pulse
The mean response variation of 10,000 PMT’s computed cell-by-cell

- The response variation of each PMT is found using the laser system
- For each cell, the response variation is defined as the mean of the gaussian fitting to the response variation distribution of the channel associated with the cell
- Observed down-drift mostly affects cells of the inner radius (A13 cells and cells in the E4 region), which are cells with higher current

Figure 7. Evolution of Down-drift of A13 cells

Laser PMT response since the start of p-p collisions

*Performed by the Pisa group, presented at New Developments In Photodetection 2017
Charge Injection System

- The CIS constant gives the relation between the value of a charge and the peak amplitude in the response of Analog to Digital Converters (units of ADC counts/pC)
- Charges of known values are injected by a 5.2 pF and a 100 pF capacitor
- Passive pulse shaper produces a pulse with a Gaussian shape (FWHM ≈ 50 ns)
- The pulse is split and sent through 2 different amplifiers separated by a gain of 64
- The ADC samples each pulse 7 times, each sample separated by 25 ns
- The peak of each pulse is estimated
Charge Injection System

- The process on slide 7 is repeated 60 times per charge
- Allows us to study stability

60 fitted injections for each known charge value (4 for each phase, a step of 1.7 ns)

Mean fitted amplitude for 60 injections plotted against injected charge value

Process is repeated for multiple known charge values. Slope of plot gives CIS constant (ADC/pC)
Typical Issues: Good vs Bad CIS Stability Plots

Notable issues identified by CIS: no response, stuck bits, digital errors
Trigger Scans

- Purpose: compare L1 trigger and TileCal channel response to known signals using special calibration runs
- Process
  - Charge Injection System (CIS) injects a known charge into readout electronics
  - Digital responses from ADC cards and adders are measured and compared to the injected energy
  - Channels are flagged (“no gain” or “half gain”) if they show different responses in L1Calo or TileCal digital signals with respect to known charge

Readout Flow Chart
Maintenance

- Common maintenance issues in TileCal and L1Calo
- Approach to maintenance
- UChicago tech duties
  - Troubleshooting
  - Services
  - Playing fetch
TileCal Maintenance Objectives

- Perform Tile Calorimeter detector hardware repairs in the ATLAS cavern
  - Troubleshoot and fix drawers (problems often identified by calibration system: CIS, Laser, Cesium)
  - Test drawers onsite using MobiDICK, a mobile test bench
- Perform Tile Calorimeter racks hardware replacements in ATLAS USA15 technical cavern (often L1Calo issues)
- Study causes of hardware failures
- Determine performance status of replaced front-end electronics
TileCal Drawer Schematic

Readout Flow Chart

L1Calo Readout

Tile Digitized Readout

Physics event

Trigger adder

PMT

3-in-1

Digitizer

Interface board

ROD

energy, time

High Level Trigger
TileCal Maintenance Issues 2017

TileCal issues categories:

- Noise Issues
- No CIS pulses
- No/Bad Cesium calibration
- Potential gain switch issues
- Cooling issues
- Integrator issues

*Note that sometimes reasons for “bad channels” cannot be identified prior for opening the drawer… LBA52 for example was simply categorized as “DEAD”

Order of priorities: “Maintenance Triage”

- 99% of discarded channels:
  - LBA52 - DAQ data discarded, drawer OFF since September
  - LBC05 - Cooling issues, drawer OFF since August
  - LBA65 - ¼ of the drawer OFF
- Else:
  - CIS - Integrator issue: Bad 3-in-1 cards resulting in 50% drop in integrator response
  - Modules with high rate of digital errors (about 1% of masked channels)
  - LBC48 in emergency mode
TileCal
Testbeam
Test Beam aims to evaluate the performances of different prototypes for future upgrades to the ATLAS hadron calorimeter.
- LBC02 is the Demonstrator module.
- LBA01, LBC01, and EBC03 are Legacy modules.
- LBA02 is Fatalic, QIE.

**TileCal Test Beam setup**

- Positive eta
- Negative eta

![Diagram of TileCal Test Beam setup](image)
TileCal Test Beam

2 Cherenkov counters
Separate p/π/e for E(beam) ≤ 50 GeV

2 wire chambers
Measure beam impact point on TileCal

TileCal modules
M0, LB, EB

2 Trigger scintillators

Muon hodoscope
Phase II Upgrade

- **Upgraded 3-in-1:**
  - 12-bits ADC instead of 10-bit
  - Pulse shaper (50 ns FWHD)
  - **Advantages:** compatible with legacy system and current analog TileCal trigger, is a proven technology!

- **QIE (Charge Integrator and Encoder)**
  - 25 ns gated integrator
  - Application-Specific Integrated Circuit (ASIC) dynamic range achieved through 4 non-linear gain ranges
  - **Advantages:** proven radiation hard technology (currently used in CMS)

- **FATALIC (Front-end ATLAS tile Integrated Circuit)**
  - Pulse Shaper
  - ASIC with dynamic range achieved through 3 gain ranges
  - **Advantages:** high tolerance for radiation, fewer components

For the high-luminosity LHC, detector components do not need replacements, but readout electronics do!
QIE

- Does NOT shape the PMT pulse for digitization
- Instead, directly integrates PMT anode current in 25 ns intervals
- Each integration throughout the pulse is a “sample”
- Total charge of PMT pulse is obtained from the sum of QIE samples

<table>
<thead>
<tr>
<th>Input Charge</th>
<th>Range</th>
<th>ADC Code</th>
<th>Sensitivity (Q/bin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-16 fC – 34 fC</td>
<td>0</td>
<td>0 – 31</td>
<td>1.55 fC/bin</td>
</tr>
<tr>
<td>34 fC – 158 fC</td>
<td>0</td>
<td>32 – 71</td>
<td>3.1 fC/bin</td>
</tr>
<tr>
<td>158 fC – 419 fC</td>
<td>0</td>
<td>72 – 113</td>
<td>6.2 fC/bin</td>
</tr>
<tr>
<td>419 fC – 592 fC</td>
<td>0</td>
<td>114 – 127</td>
<td>12.4 fC/bin</td>
</tr>
<tr>
<td>517 fC – 915 fC</td>
<td>1</td>
<td>0 – 31</td>
<td>12.4 fC/bin</td>
</tr>
<tr>
<td>915 fC – 1910 fC</td>
<td>1</td>
<td>32 – 71</td>
<td>24.8 fC/bin</td>
</tr>
<tr>
<td>1910 fC – 3990 fC</td>
<td>1</td>
<td>72 – 113</td>
<td>49.6 fC/bin</td>
</tr>
<tr>
<td>3990 fC – 5380 fC</td>
<td>1</td>
<td>114 – 127</td>
<td>99.2 fC/bin</td>
</tr>
<tr>
<td>4780 fC – 7960 fC</td>
<td>2</td>
<td>0 – 31</td>
<td>99.2 fC/bin</td>
</tr>
<tr>
<td>7960 fC – 15.9 pC</td>
<td>2</td>
<td>32 – 71</td>
<td>198.4 fC/bin</td>
</tr>
<tr>
<td>15.9 pC – 32.6 pC</td>
<td>2</td>
<td>72 – 113</td>
<td>396.8 fC/bin</td>
</tr>
<tr>
<td>32.6 pC – 43.7 pC</td>
<td>2</td>
<td>114 – 127</td>
<td>793.6 fC/bin</td>
</tr>
<tr>
<td>38.9 pC – 64.3 pC</td>
<td>3</td>
<td>0 – 31</td>
<td>793.6 fC/bin</td>
</tr>
<tr>
<td>64.3 pC – 128 pC</td>
<td>3</td>
<td>32 – 71</td>
<td>1587 fC/bin</td>
</tr>
<tr>
<td>128 pC – 261 pC</td>
<td>3</td>
<td>72 – 113</td>
<td>3174 fC/bin</td>
</tr>
<tr>
<td>261 pC – 350 pC</td>
<td>3</td>
<td>114 – 127</td>
<td>6349 fC/bin</td>
</tr>
</tbody>
</table>
CIS Calculation: A New Method

- Charge Injection System for Demonstrator works in a similar way to the system currently implemented in ATLAS
- Demonstrator has the option of using 12-bit ADCs
Projective muon studies

- Helps evaluate electronics performance of the Demonstrator since muon signals are close to electronic noise
- Selects muon events from an unbiased 12-bit response in a layer by placing no energy cuts on the layer studied
  - Muons do not deposit much of their energy along the beamline, so a signal in the first cell penetrated should be detected as a signal in later cells
  - To find a muon signal in a given layer, cuts on energies are placed on remaining layers in the beamline
  - Pedestal found from a reconstructed signal in a given layer from a run with no beam in the Demonstrator
Projective Muon Studies

- Total energy in each layer found
- Muon signal peaks are approximately proportional to track length

<table>
<thead>
<tr>
<th>Cell</th>
<th>response (pC)</th>
<th>EM Scale</th>
<th>Cesium (diff/cos20)</th>
<th>response/track l (pC/cm)</th>
<th>response/track l (MeV/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell A</td>
<td>0.421731</td>
<td>0.00105</td>
<td>1</td>
<td>31.925</td>
<td>0.013209917</td>
</tr>
<tr>
<td>Cell BC</td>
<td>1.24018</td>
<td>0.001013</td>
<td>1</td>
<td>89.391</td>
<td>0.013873667</td>
</tr>
<tr>
<td>Cell D</td>
<td>0.674223</td>
<td>0.000987</td>
<td>1.2</td>
<td>40.439</td>
<td>0.016672694</td>
</tr>
<tr>
<td>Three layers</td>
<td>2.35463</td>
<td></td>
<td>161.755</td>
<td></td>
<td>0.014556766</td>
</tr>
</tbody>
</table>

Total Response = 14.91 +/- 0.08 MeV/cm, consistent with monte carlo!
Preliminary QIE results

- QIE reconstructs energy as the sum of integrated charge
- To select muon events for QIE, same selection method followed as for 3-in-1
- Pedestal-signal separation could be determined for both electronic options
Preliminary QIE results

Compare muon signals for 3-in-1 and QIE for QIE’s four non-linear gain ranges

QIE energy increased by 11.7%
Conclusions

ATLAS detector

- Three calibration systems for different readouts
- Newly reintroduced L1Calo-TileCal crosscheck

Test Beam

- Implemented CIS
- Compared muon signals for 3-in-1 and QIE
Backup Slides
Two methods were developed to measure the laser coherence constant “k” in the formula to statistically measure the absolute gain $G_i$ of a PMT “i”

$$f \cdot g \cdot e = \frac{\text{var}(q)}{<q>} - f \cdot \kappa \cdot <q>$$

$$\kappa = \frac{\text{Cov}(q_i, q_j)}{<q_i><q_j>}$$

1) covariance method

(2) energy scan method

- The difference between PMT response and absolute gain is evident in both the ATLAS detector and test bench
- Difference can include several effects like cathode Q.E. loss, PMT window transparency degradation, and systematic effects (ex. aging of fibers)
PMT response since the start of p-p collisions

<table>
<thead>
<tr>
<th>Most exposed cell per layer</th>
<th>PMT integrated anode charge (C)</th>
<th>Measured PMT response loss (%)</th>
<th>PMT integrated anode charge (C)</th>
<th>Measured PMT response loss (%)</th>
<th>PMT integrated anode charge (C)</th>
<th>Measured PMT response loss (%)</th>
<th>PMT integrated anode charge (C)</th>
<th>Measured PMT response loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A13</td>
<td>5</td>
<td>-5</td>
<td>25</td>
<td>-15</td>
<td>50</td>
<td>-20</td>
<td>500</td>
<td>-50</td>
</tr>
<tr>
<td>B11/C10</td>
<td>1.5</td>
<td>&gt;-3</td>
<td>8</td>
<td>-5</td>
<td>15</td>
<td>-7</td>
<td>150</td>
<td>-15</td>
</tr>
<tr>
<td>D4</td>
<td>1</td>
<td>&gt;-2</td>
<td>5</td>
<td>-2.5</td>
<td>10</td>
<td>-6</td>
<td>100</td>
<td>-9</td>
</tr>
</tbody>
</table>
CIS Update procedure

- Updates are done through the TUCS framework on a monthly basis.
- Running an update gives a SQLite file with the new CIS constants.
- Stability plots are only included in the update if they:
  - Have more than a .5% shift from the previous constant
  - Have a quality flag
  - Already have a COOL status flag
- The update also produced a text file with information about the ADCs with new CIS constants.
- Plots are scanned for any major changes or issues. These ADCs are all investigated further.
- New COOL statues are assigned.
Quality Flags

- Quality flags are made automatically when running the update.
- They are triggered when an ADC fails a certain quality shown in the table to the right.
- Common non-fatal flags:
  - Fail likely calib.
  - Large Injection RMS
  - Low Chi2
- Common fatal flags:
  - Digital errors
  - Stuck bit

<table>
<thead>
<tr>
<th>Flag</th>
<th>Location</th>
<th>Passed If...</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Response</td>
<td>qflag bit 1</td>
<td>At least one successful injection readout</td>
</tr>
<tr>
<td>Fail Likely Calib.</td>
<td>qflag bit 3</td>
<td>CIS constant within 6.23% of detector-wide mean</td>
</tr>
<tr>
<td>Fail Max. Point</td>
<td>qflag bit 4</td>
<td>≥ 1 point in fit range &gt; 600 ADC counts</td>
</tr>
<tr>
<td>Large Injection RMS</td>
<td>qflag bit 5</td>
<td>RMS of all fixed-charge injections in fit range ≤ 5</td>
</tr>
<tr>
<td>Digital Errors</td>
<td>qflag bit 6</td>
<td>All digital error checks passed</td>
</tr>
<tr>
<td>Low Chi2</td>
<td>qflag bit 7</td>
<td>Linear fit $\chi^2 &gt; 2 \times 10^{-6}$</td>
</tr>
<tr>
<td>Edge Sample</td>
<td>qflag bit 8</td>
<td>No events in fit range w/ 1st or 7th sample as max</td>
</tr>
<tr>
<td>Next to Edge Sample</td>
<td>qflag bit 9</td>
<td>No events in fit range w/ 2nd or 6th sample as max</td>
</tr>
<tr>
<td>Stuck Bit</td>
<td>qflag bit 10</td>
<td>No stuck bits in readout chain detected</td>
</tr>
<tr>
<td>Unstable</td>
<td>TUCS</td>
<td>ADC CIS const. RMS/Mean &lt; 0.39%</td>
</tr>
<tr>
<td>Mean Deviation</td>
<td>TUCS</td>
<td>CIS constant within 5% of ADC time period avg.</td>
</tr>
<tr>
<td>Default Calibration</td>
<td>TUCS</td>
<td>Default CIS constant not used in database</td>
</tr>
<tr>
<td>Outlier</td>
<td>TUCS</td>
<td>CIS const. &lt; 6 and &gt; 15% away from det. avg.</td>
</tr>
<tr>
<td>DB Deviation</td>
<td>TUCS</td>
<td>Measured and database const. differ by &lt; 1%</td>
</tr>
</tbody>
</table>