Tile Calorimeter Calibration

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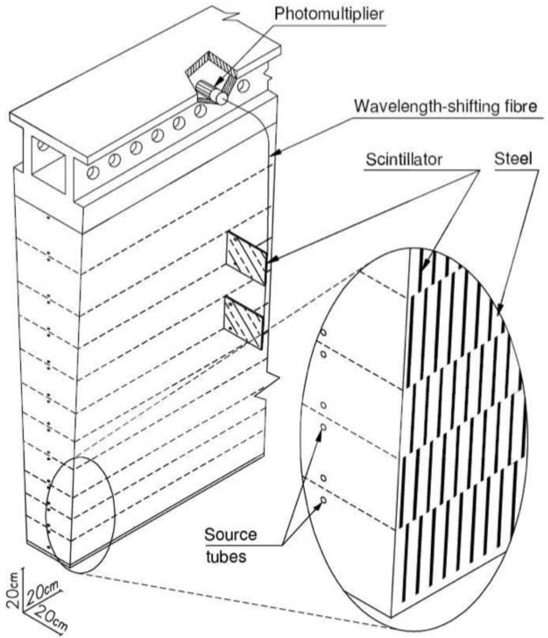
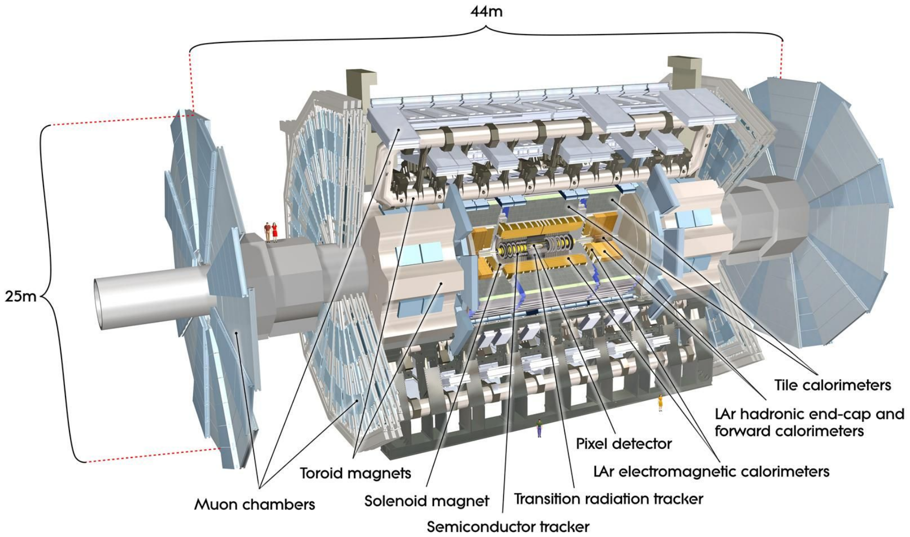
Today:

- 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)





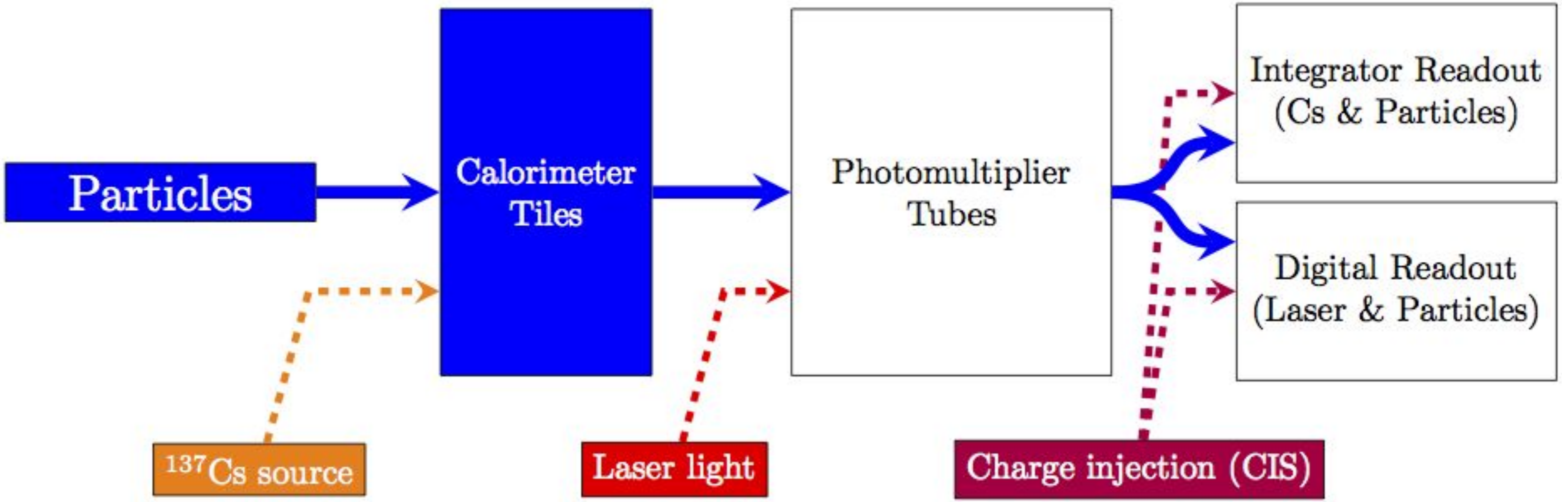
- Plastic scintillator tiles sample the energy within the detector
- Optical fibers transmit the light to PMT cells located inside Drawers

Tile Calorimeter Calibration

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

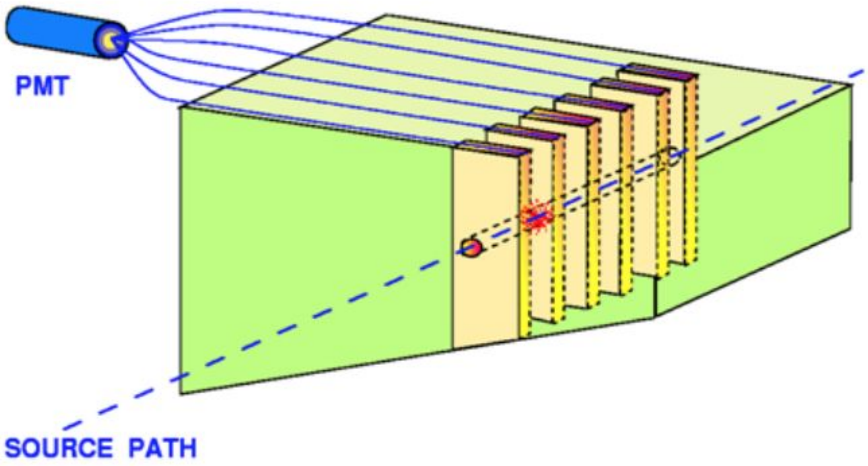
  $E_{channel}$ [GeV] = A [ADC] · $C_{ADC\rightarrow pC}$ · $C_{pC\rightarrow GeV}$ · $\varepsilon_{C\ s}$ · ε_{Laser}

- Each system tests a specific element of the readout chain



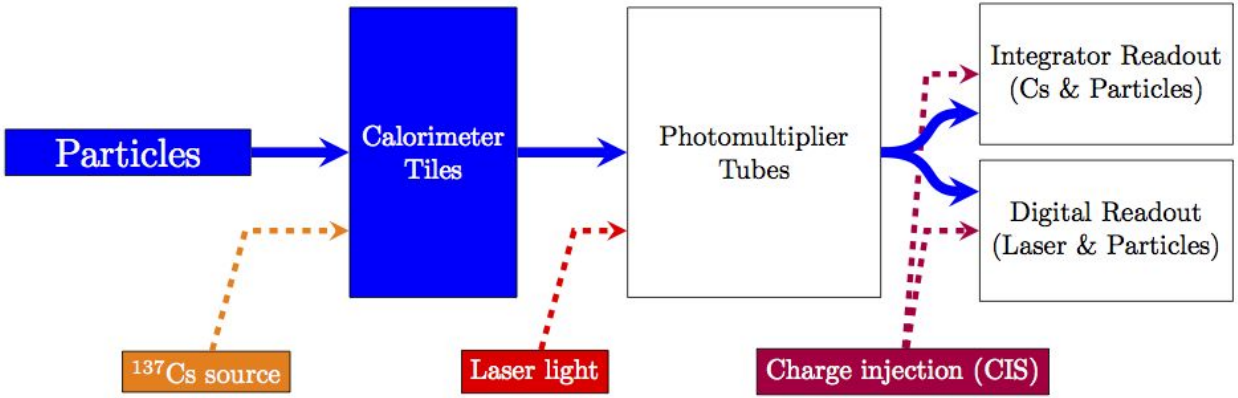
Cesium

- 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



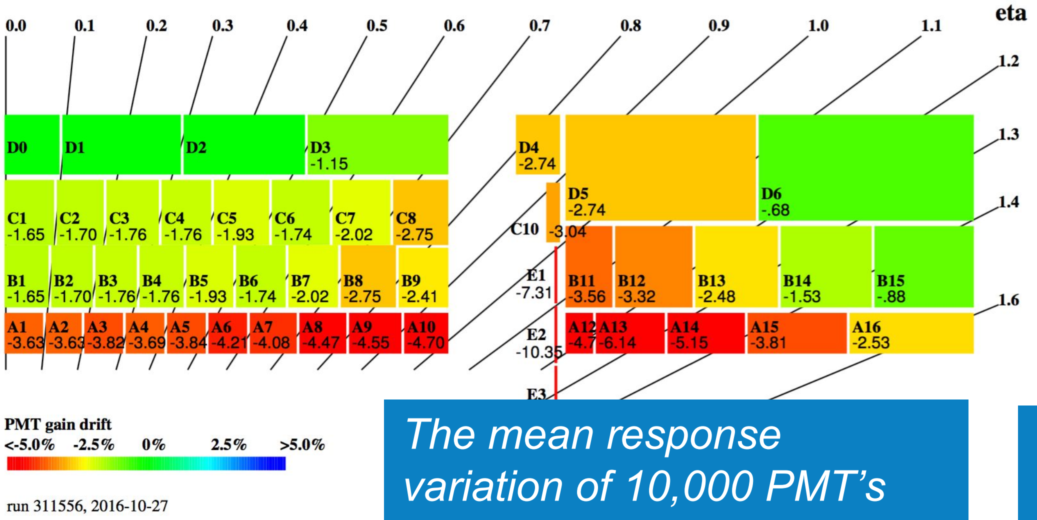
Laser

- 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



Laser PMT response since the start of p-p collisions

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



The mean response variation of 10,000 PMT's computed cell-by-cell

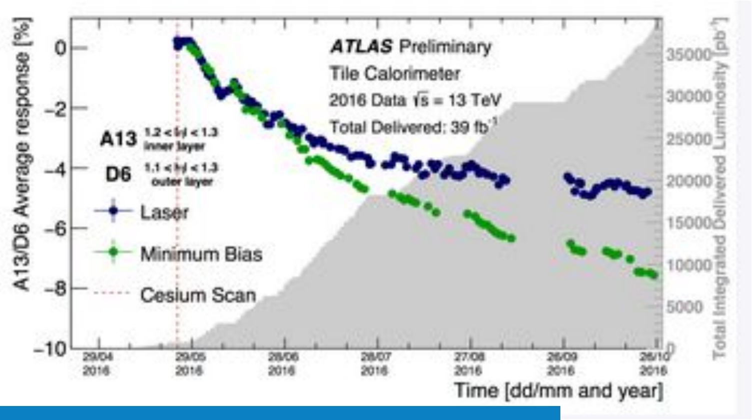
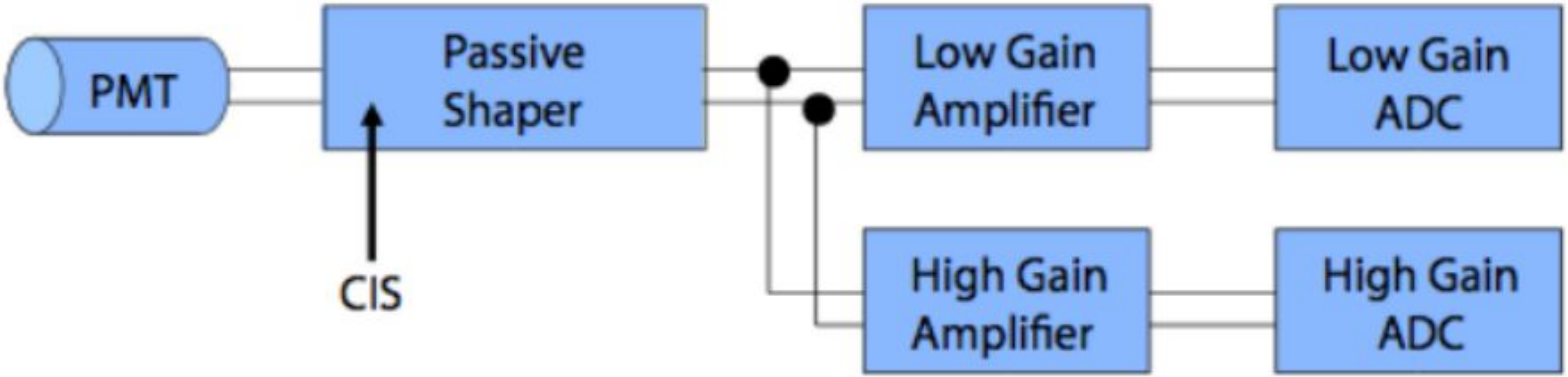


Figure 7. Evolution of Down-drift of A13 cells

- 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

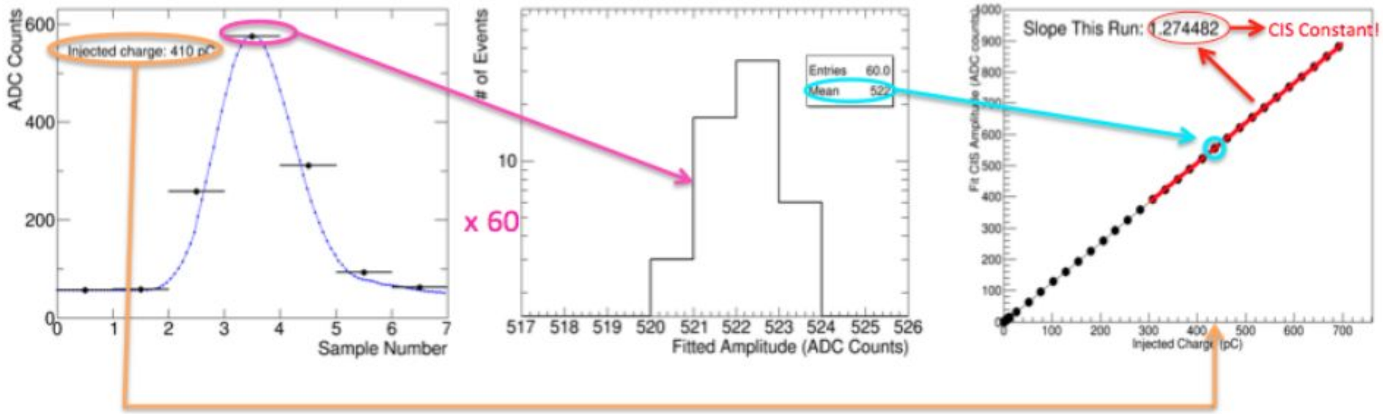
Charge Injection System

- 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

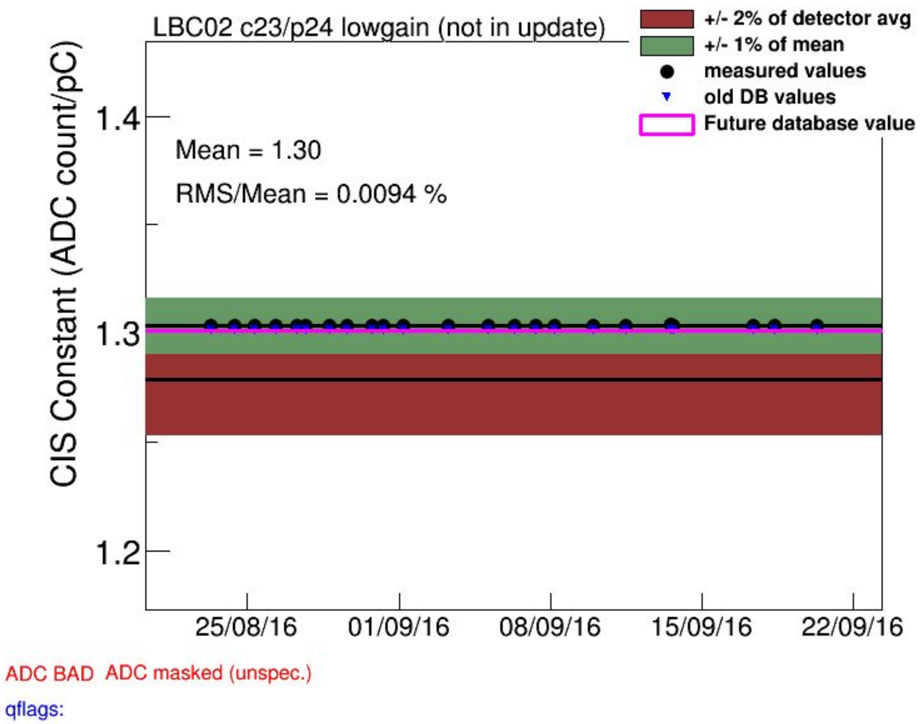


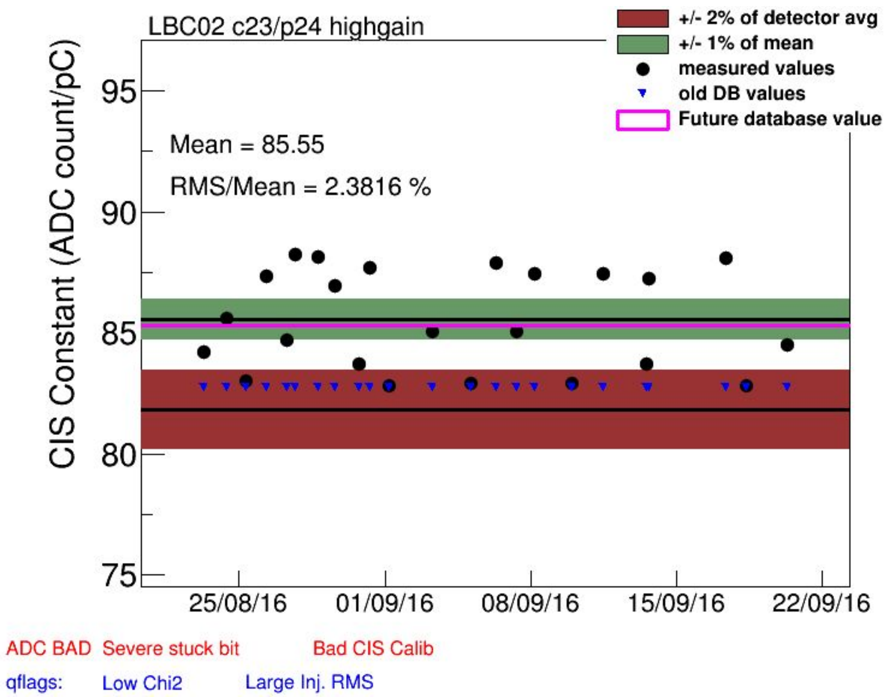
60 fitted injections for each known charge value
(4 for each phase, a step of 1.7 ns)

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



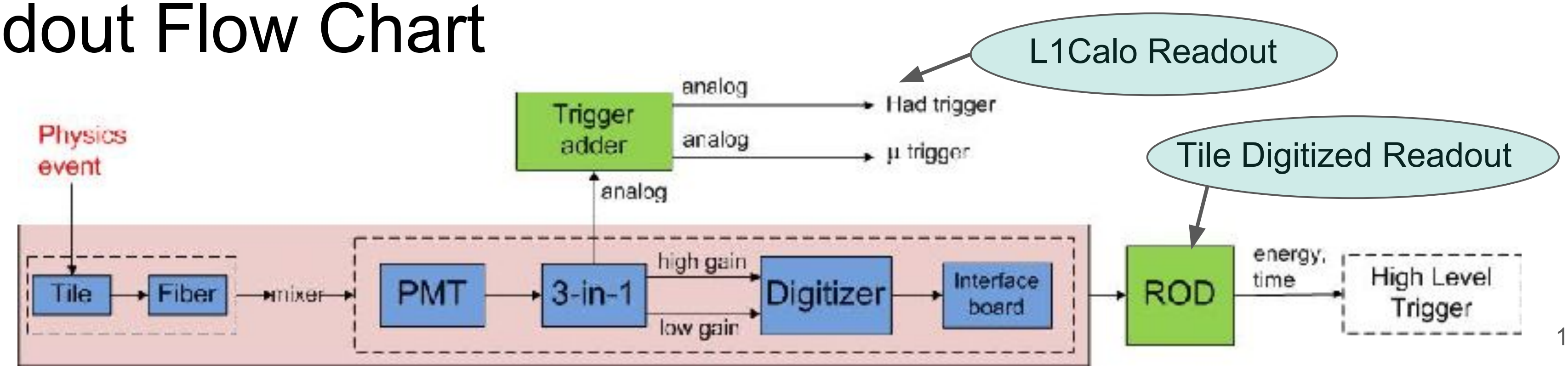


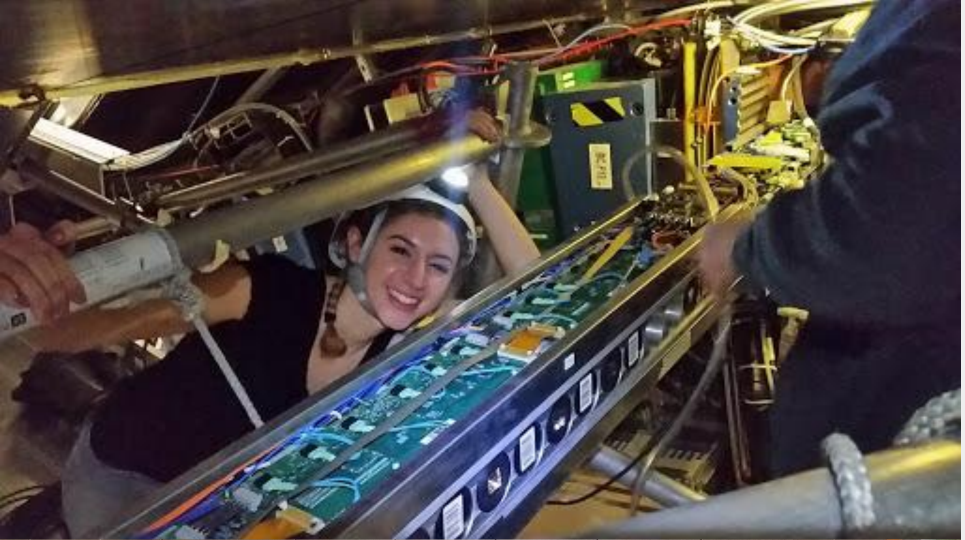
Notable issues identified by CIS: no response, stuck bits, digital errors

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





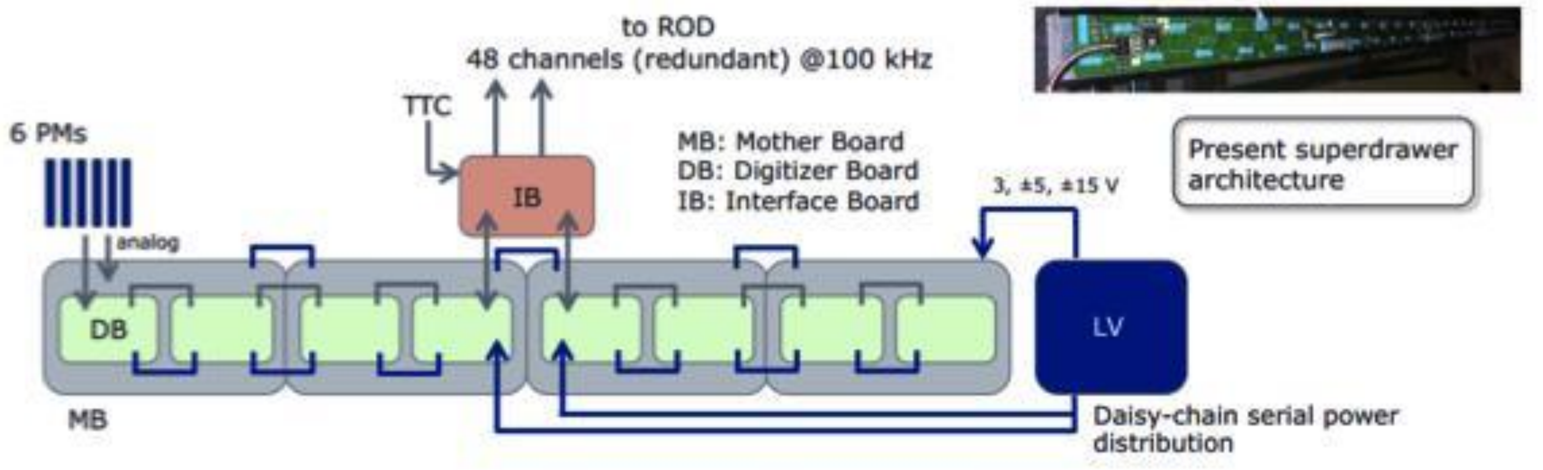
Maintenance

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

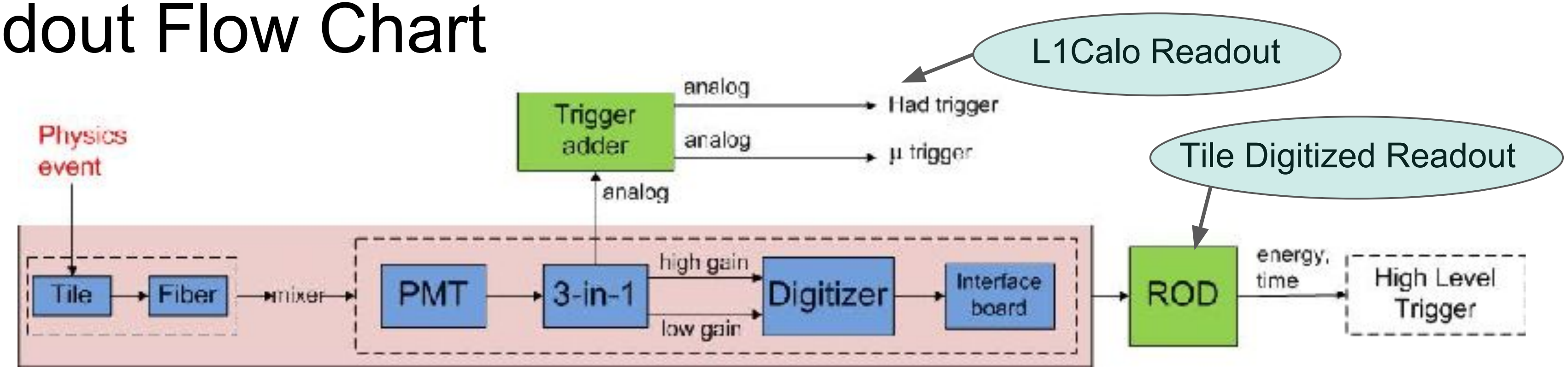
TileCal Maintenance Objectives

- 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



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”

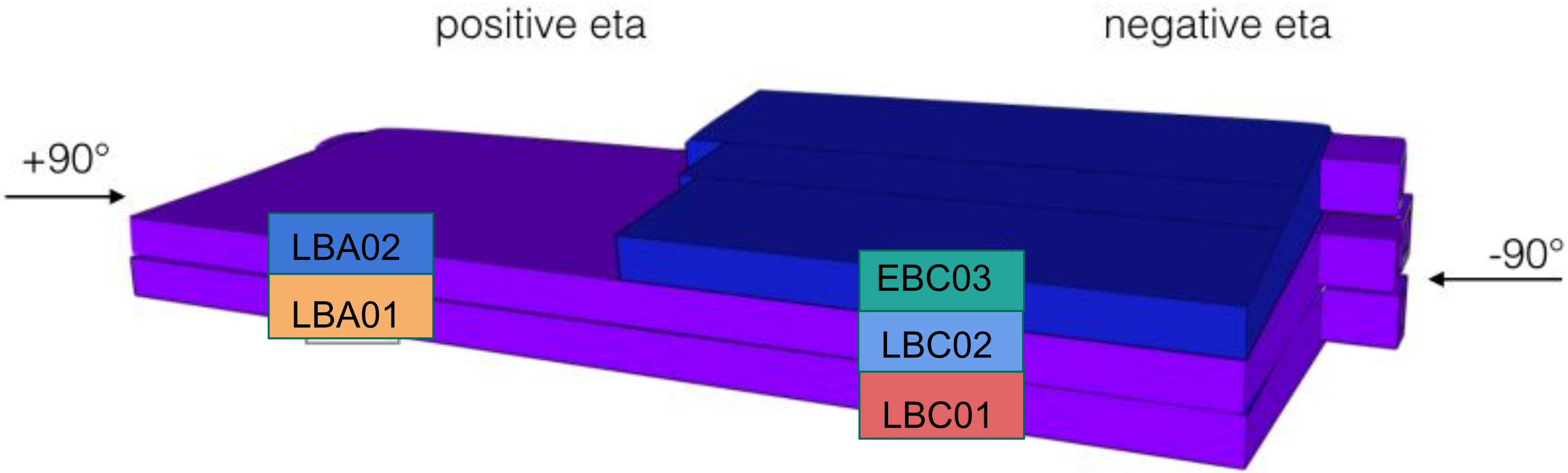
Order of priorities: “Maintenance Triage”

- **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

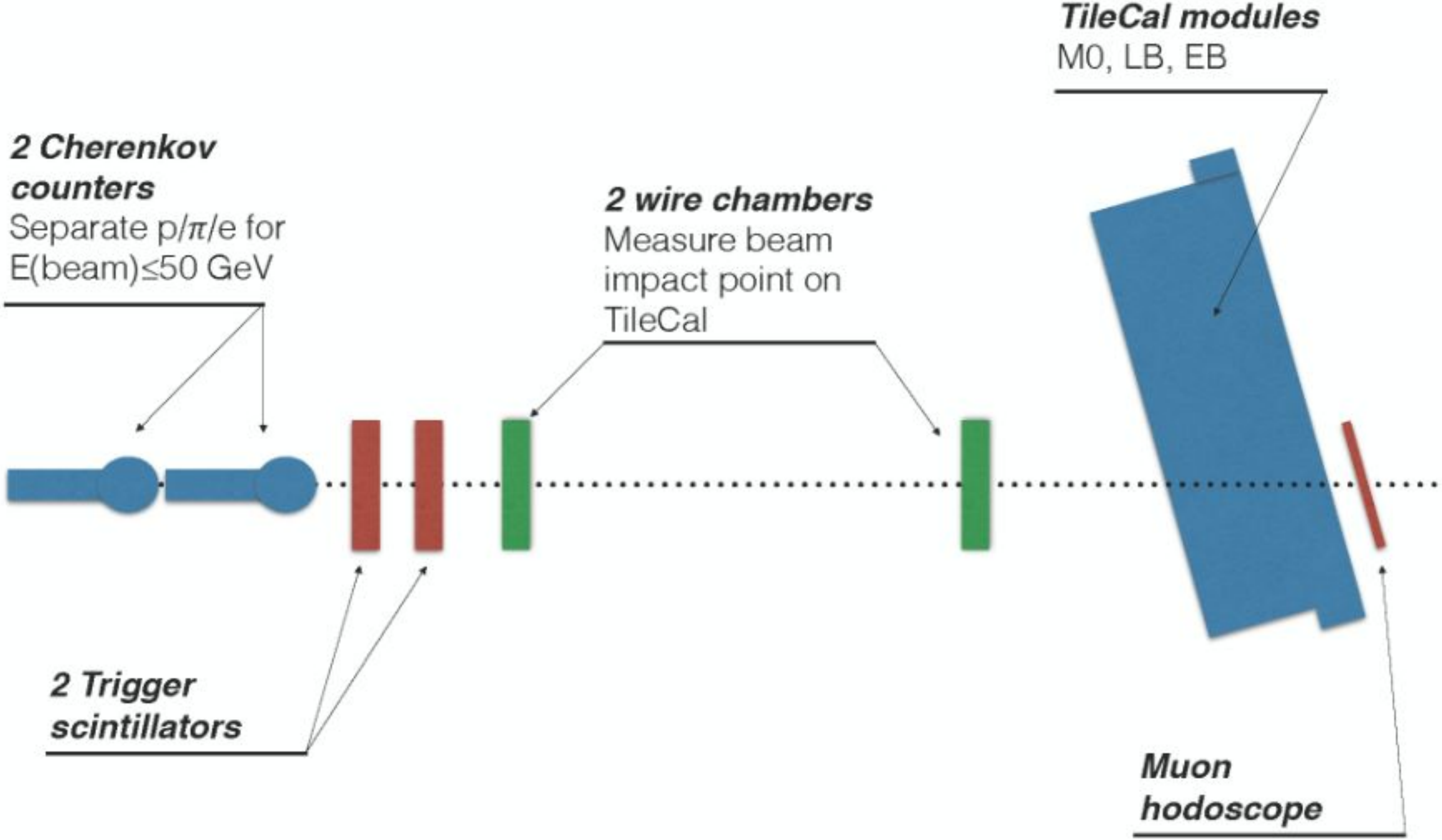
TileCal Testbeam

TileCal Test Beam setup

- 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



Phase II Upgrade

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

- 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 (<u>**C**</u>harge <u>**I**</u>ntegrator and <u>**E**</u>ncoder)
  - 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 (<u>**F**</u>ront-end <u>**AT**</u>l<u>**A**</u>s ti<u>**L**</u>e <u>**I**</u>ntegrated <u>**C**</u>ircuit)
  - Pulse Shaper
  - ASIC with dynamic range achieved through 3 gain ranges
  - **Advantages**: high tolerance for radiation, fewer components

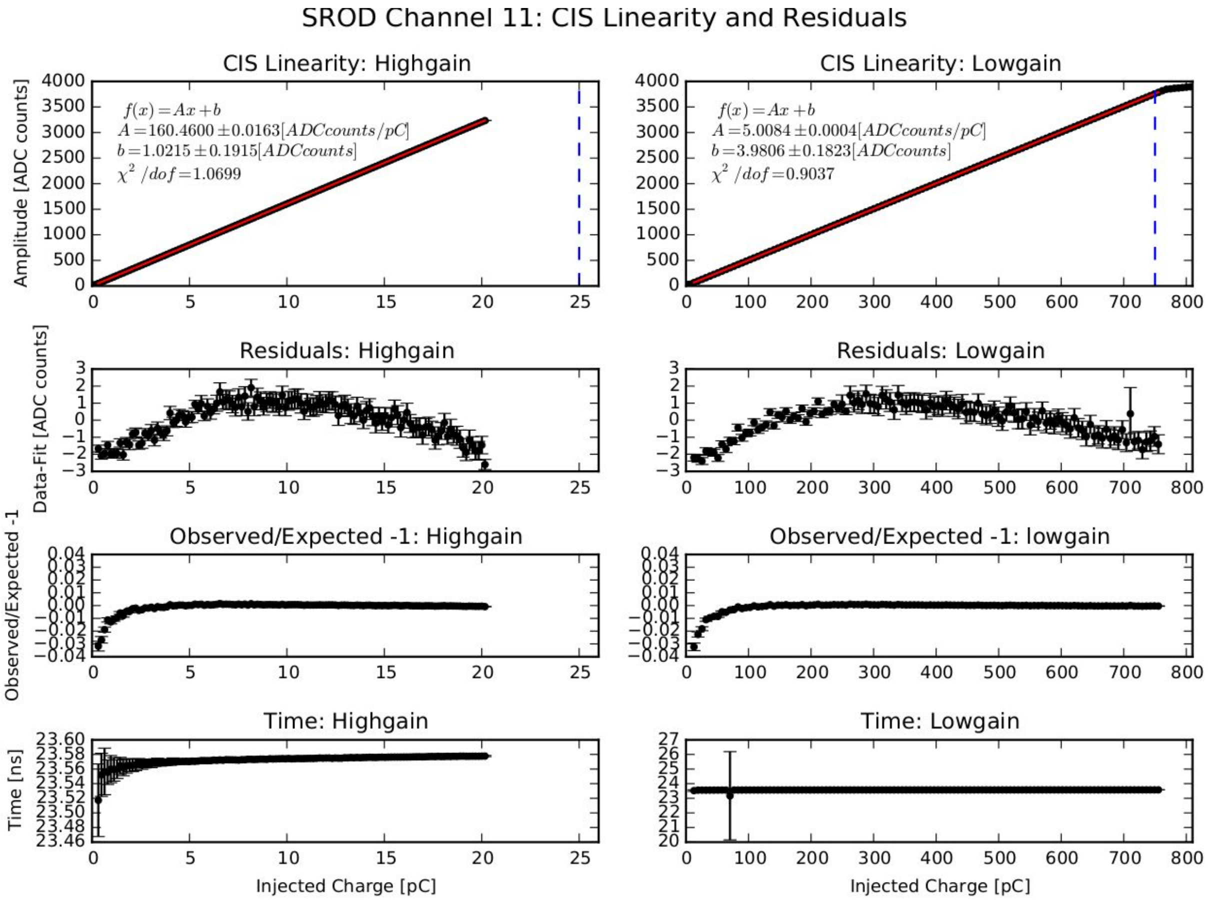
QIE

- 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

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

CIS Calculation: A New Method

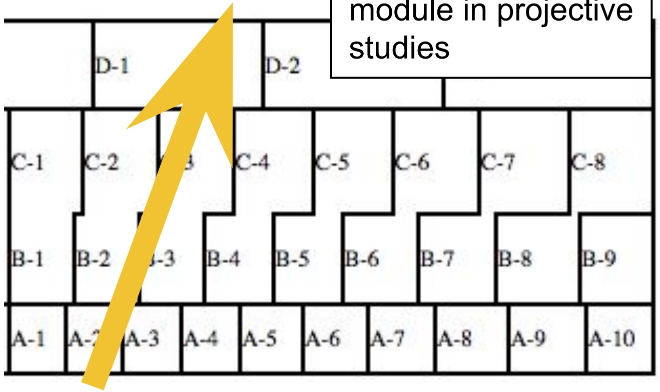
- Charge Injection System for Demonstrator works in a similar way to the system currently implemented in ATLAS
- Demonstrator has the option of using 12-bit ADCs

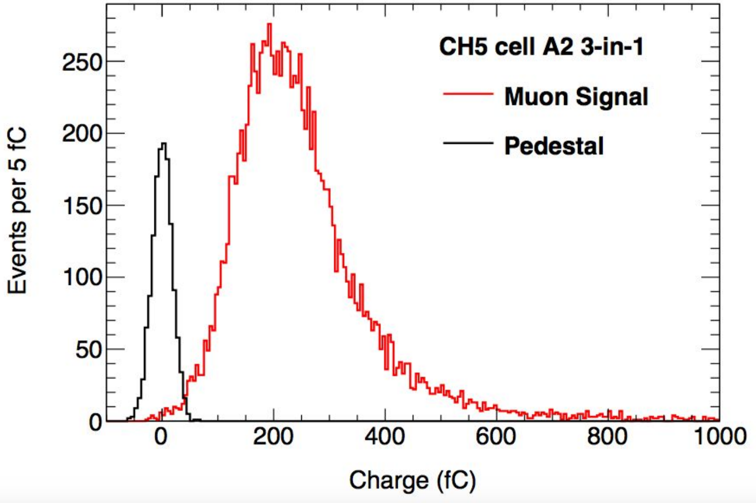


Projective muon studies

- 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 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

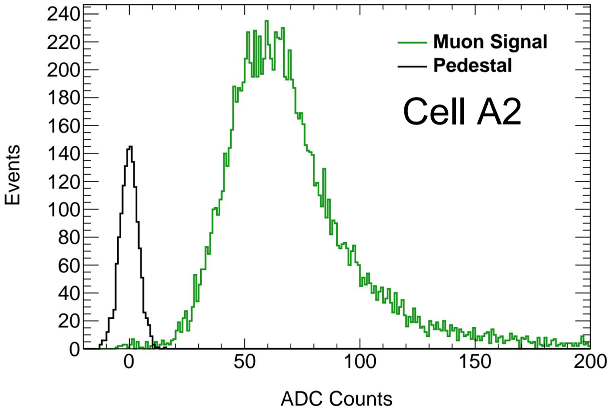
Beam penetrates all three layers of module in projective studies

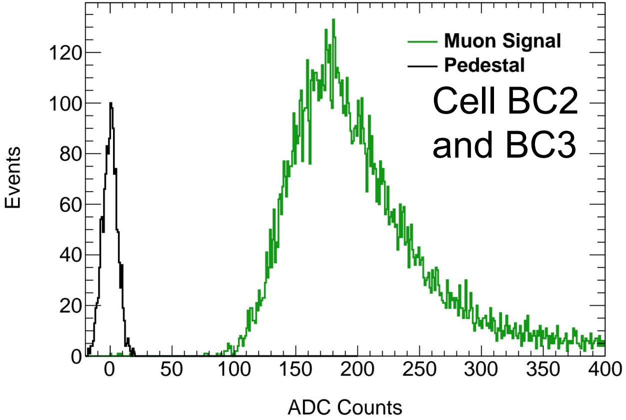


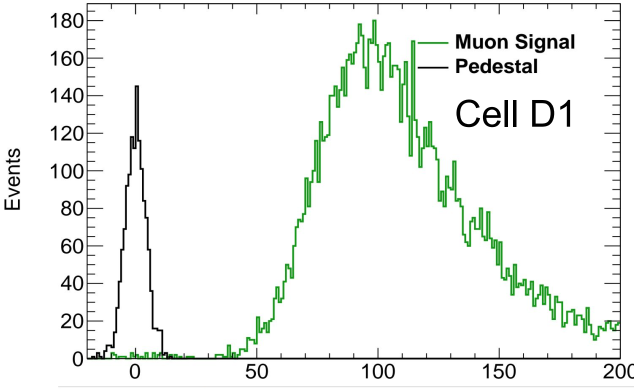


Projective Muon Studies

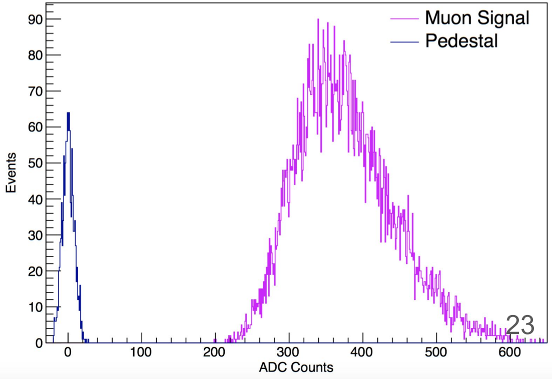
- Total energy in each layer found
- Muon signal peaks are approximately proportional to track length







Signal and Pedestal in all three layers

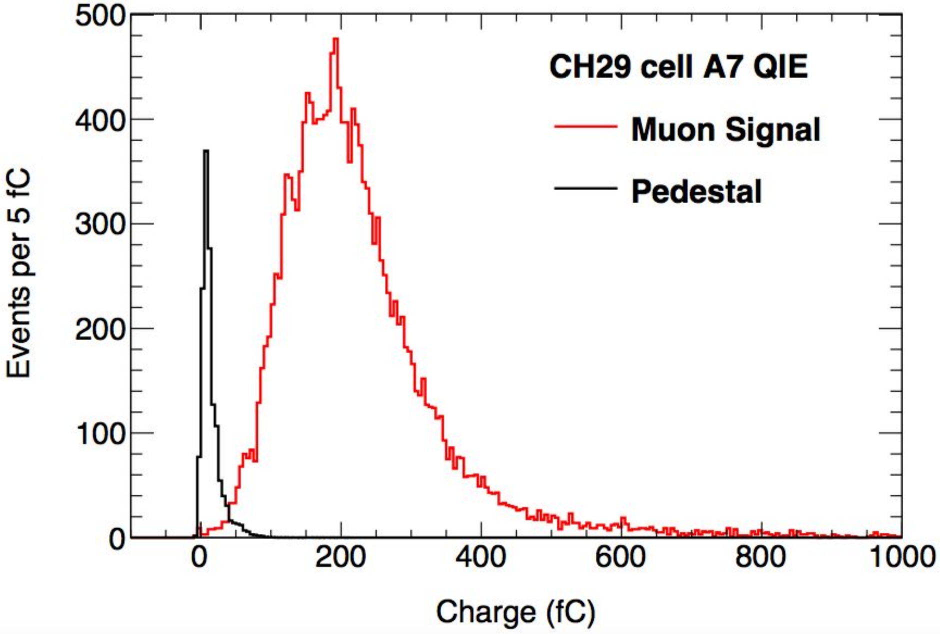


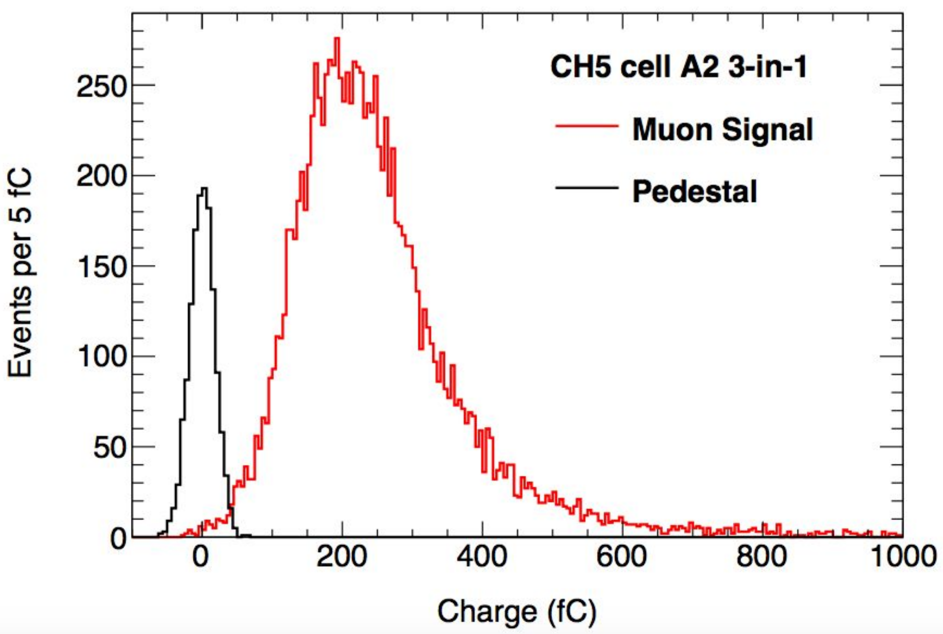
	response (pC)	EM Scale	Cesium	track length (diff/cos20)	response/track l (pC/cm)	response/track l (MeV/cm)
Cell A	0.421731	0.00105	1	31.925	0.013209917	13.82513548
Cell BC	1.24018	0.001013	1	89.391	0.013873667	15.05013571
Cell D	0.674223	0.000987	1.2	40.439	0.016672694	15.46913368
Three layers	2.35463			161.755	0.014556766	

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

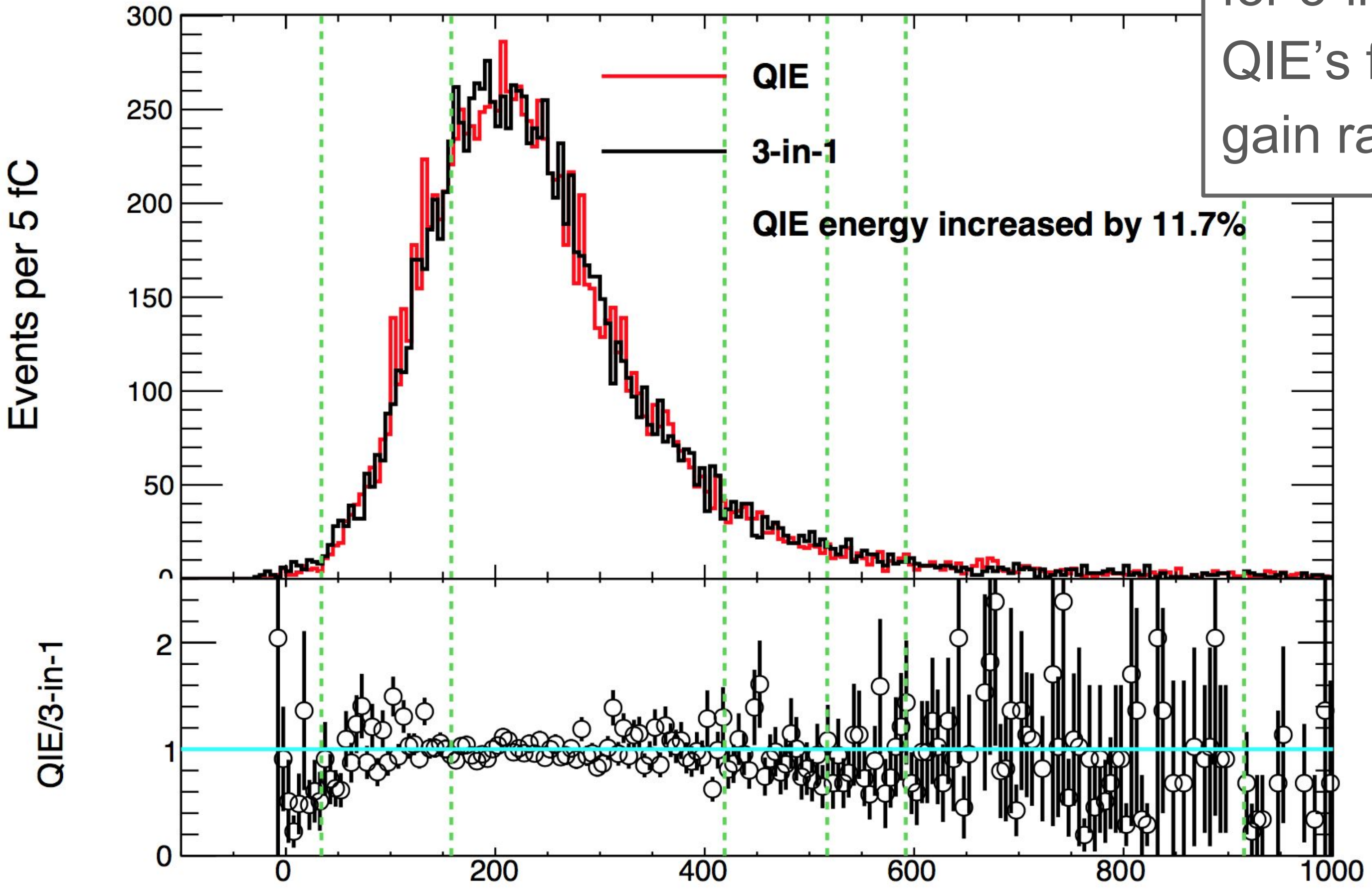
Preliminary QIE results

- 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

Conclusions

ATLAS detector

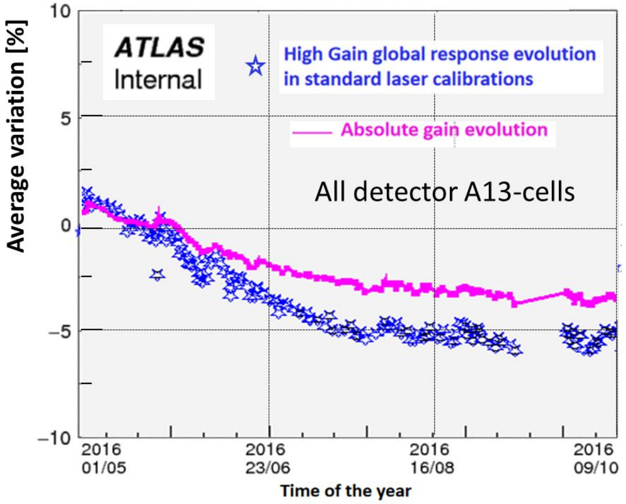
- Three calibration systems for different readouts
- Newly reintroduced L1Calo-TileCal crosscheck

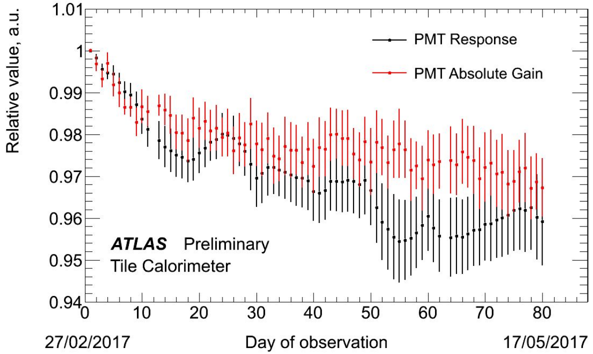
Test Beam

- Implemented CIS
- Compared muon signals for 3-in-1 and QIE

Backup Slides

PMT response since the start of p-p collisions





Two methods were developed to measure the laser coherence constant “k” in the formula to statistically measure the absolute gain Gi of a PMT “i”

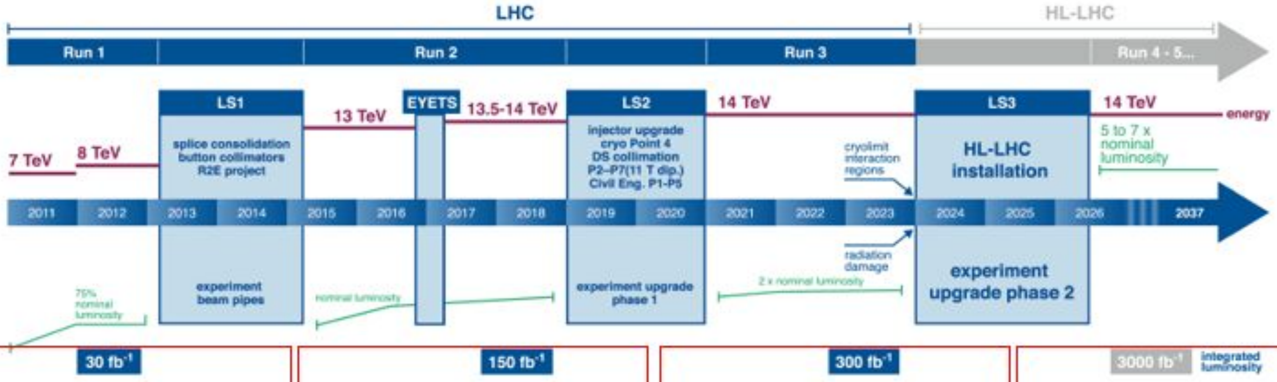
$$f \cdot g \cdot e = \frac{var(q)}{<q>} - f \cdot \kappa \cdot <q>$$

$$\kappa = \frac{Cov(q_i, q_j)}{<q_i><q_j>} \qquad \kappa = \frac{\frac{var(q_n)}{<q_n>} - \frac{var(q_m)}{<q_m>}}{<q_n> - <q_m>}$$

(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



Most exposed cell per layer	PMT integrated anode charge (C)	Measured PMT response loss (%)	PMT integrated anode charge (C)	Measured PMT response loss (%)	PMT integrated anode charge (C)	Measured PMT response loss (%)	PMT integrated anode charge (C)	Measured PMT response loss (%)
A13	5	-5	25	-15	50	-20	500	-50
B11/C10	1.5	>-3	8	-5	15	-7	150	-15
D4	1	>-2	5	-2.5	10	-6	100	-9

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

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