Cesium and Laser Calibration of ATLAS Tile Calorimeter

Engineering Physics Seminar-2018
IIT Madras

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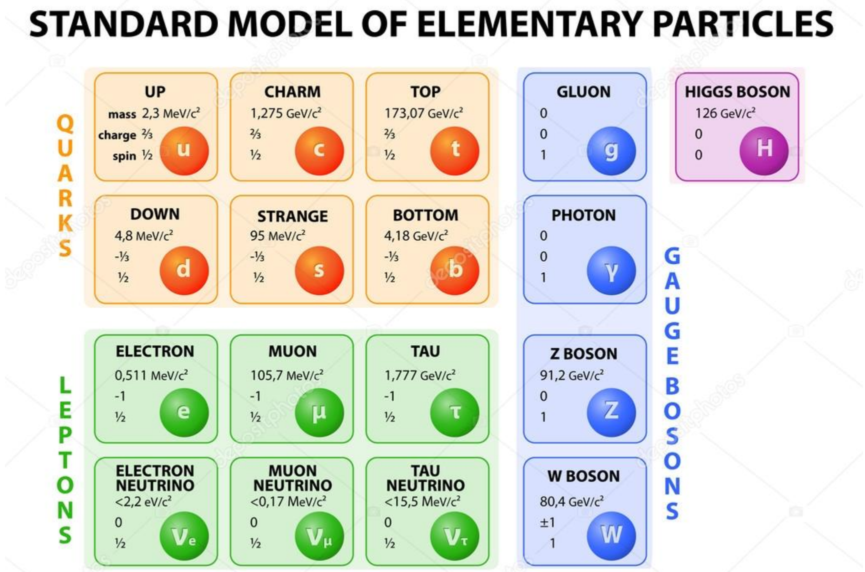
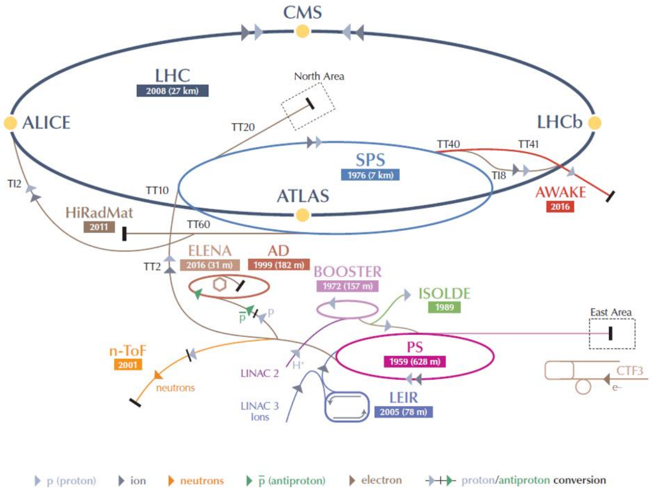
Particle Physics and the Standard Model



Infrastructure of CERN

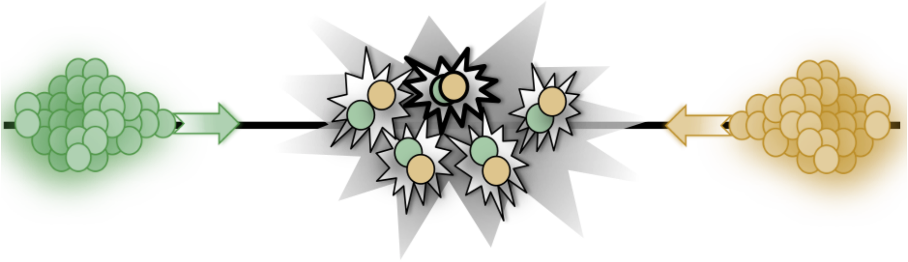


LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility AWAKE Advanced WAKefield Experiment ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials

What is an "event"?



Proton bunches
>10^{11} protons/bunch
colliding at **13 TeV** and at ~**30 MHz in Run-2**
collided at **7/8TeV** and at ~**20 MHz in Run-1**

In 2018:
Up to 60 p-p collisions / bunch crossing

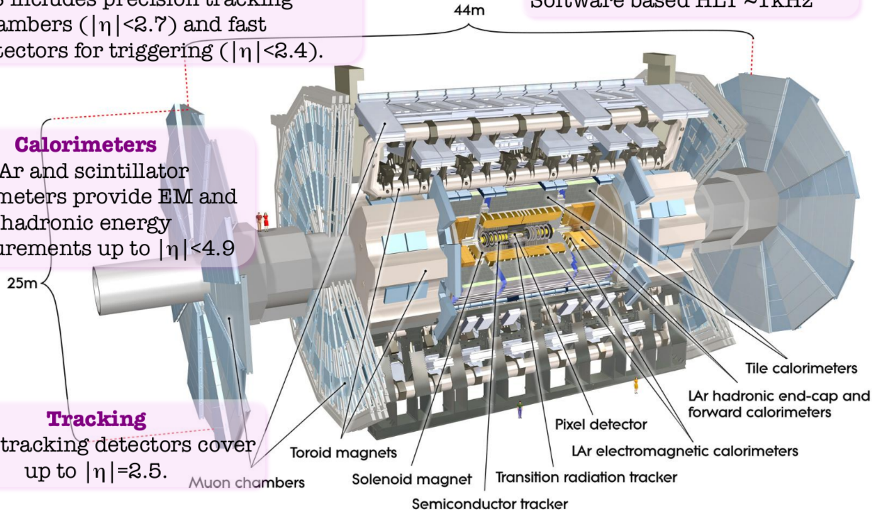
The ATLAS Detector

Muons Spectrometer
MS includes precision tracking chambers ($|\eta|<2.7$) and fast detectors for triggering ($|\eta|<2.4$).

Trigger
Hardware based L1 ~100kHz
Software based HLT ~1kHz

Calorimeters
LAr and scintillator calorimeters provide EM and hadronic energy measurements up to $|\eta|<4.9$

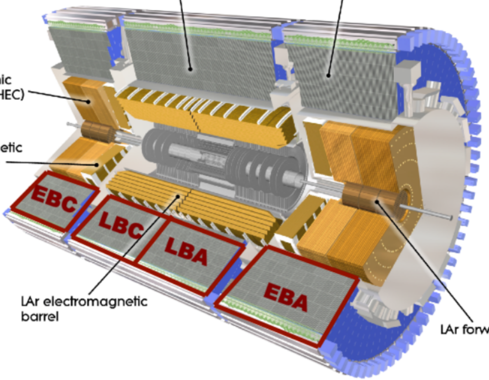
Tracking
Inner tracking detectors cover up to $|\eta|=2.5$.



Tile Calorimeter

The **ATLAS Tile calorimeter** (**TileCal**) is the central section of the ***hadronic calorimeter***.

- *Sampling calorimeter using iron plates as absorber and scintillating tiles as active medium.*
- *3 sections: Long Barrel (2 readout regions: **LBA**, **LBC**) and two Extended Barrels (**EBA**, **EBC**).*
  - *Long Barrel: 0 < $|\eta|$ < 1.0*
  - *Extended Barrel: 0.8 < $|\eta|$ < 1.7*
- *The readout is segmented into **~5000 cells** (longitudinally and transversally), each read by two PMTs.*



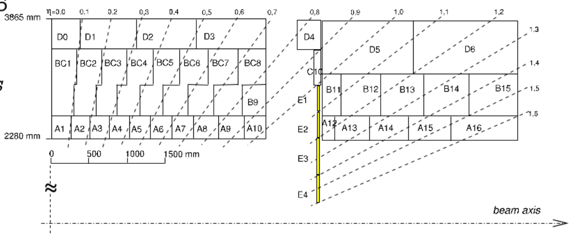
TileCal *provides important information for reconstruction of hadrons, jets, hadronic decays of tau leptons and missing transverse energy.*
Hadron energy resolution for jets: $\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\%$

Tile Calorimeter

Each partition is divided into **64 symmetric φ slices** (modules), with 45 instrumented channels in LB modules and 32 channels in EB modules.

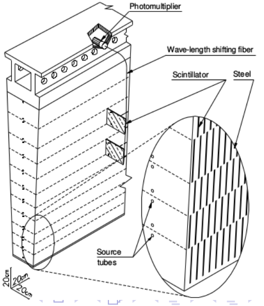
***η and radial structure** of **TileCal** cells*

- *Radially: 3 longitudinal layers (total thickness of ~7.4λ).*
  - *A-cells closest to beam axis, followed by BC- and D-cells.*
  - *E-cells installed in the gap/crack region (1.0 < |η| < 1.6).*
- η−φ granularity: $\Delta\eta\times\Delta\varphi = 0.1\times0.1$

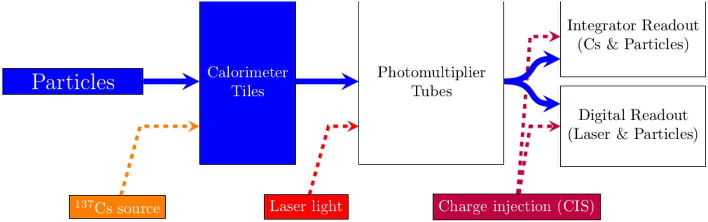


Optical readout of signals in TileCal:

- *Light produced in **scintillating tiles**.*
- *Readout via **WLS fibres** connected to both edges of the scintillating tiles.*
- *Converted into electric currents by the **PMTs**.*
  - *Their signal is shaped and amplified with two gains (LG, HG). Dynamic range: ~10 MeV to ~800 GeV.*



Calibration Systems



The reconstructed energy is derived from the raw response:

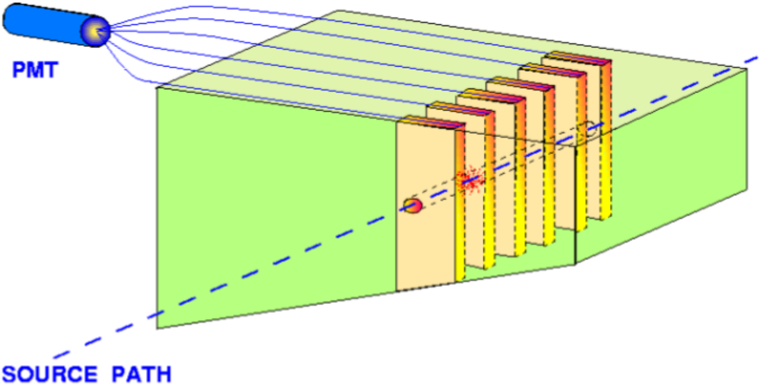
$$E(\mathrm{GeV}) = A(\mathrm{ADC}) \cdot C_{\mathrm{ADC}\to\mathrm{pC}} \cdot C_{\mathrm{pC}\to\mathrm{GeV}} \cdot C_{\mathrm{Cesium}} \cdot C_{\mathrm{Laser}}$$

Cell response is not constant in time due to the PMT gain variation and scintillator degradation due to the exposure to beam.

Systems used for **calibration** in TileCal

- **Charge Injection System** (CIS):
  - Calibrates the response of ADCs (*electronics*): $\mathbf{C_{ADC\to pC}}$.
- **Cesium system**:
  - Calibrates optical components and PMT gains: $\mathbf{C_{Cesium}}$.
- **Laser System**:
  - Calibrates variations due to electronics and PMTs: $\mathbf{C_{Laser}}$.
- **Minimum Bias System** (MB):
  - Monitors beam conditions, TileCal optic components and PMT gains.
- $\mathbf{C_{pC\to GeV}}$: measured during dedicated test beam campaigns.

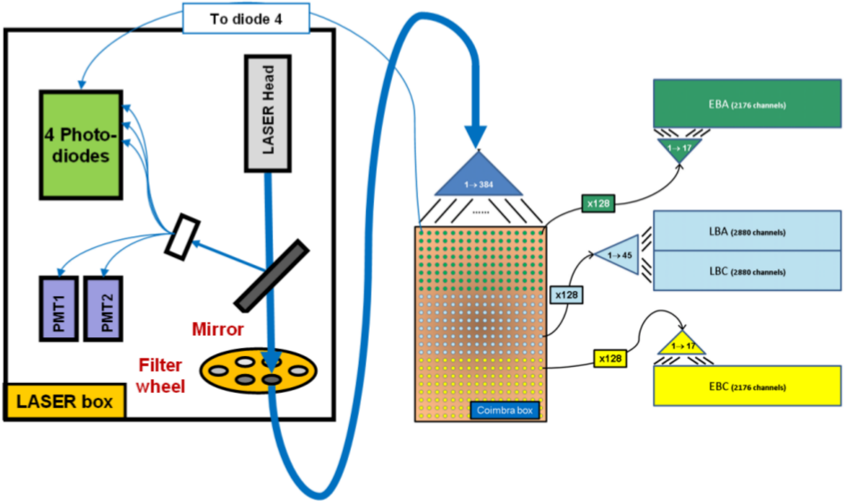
Schematic of Cesium Calibration System



Functions of Cesium Calibration

- The Cesium system is based on three moveable radioactive sources ($t_{1/2} \approx 30$ years) using a hydraulic control (through a system of steel tubes).
- The 137-Cs γ-sources move inside the calorimeter, emitting 0.662 MeV photons to illuminate the scintillators.
- The produced light in each tile induces a signal on the associated PMTs and is read out with a special electronic system (so-called the Integrator).
- Any variation seen by the cesium system in one channel between two measurements can be attributed either to a modification of a detector component behavior (for example the **ageing of scintillators**), or to a **gain variation of the PMTs**.

Schematic of Laser Calibration System



Functions of Laser Calibration

- Monitors the 9852 photomultipliers and the read-out electronics used in the detector to measure the energy deposited by particles
- Frequency-doubled infrared laser emits a 532 nm green light beam, closed to the light wavelength (480 nm) induced by particles and seen by the PMTs.
- The laser calibration constant C_{Laser} is computed using the response of the channels to the laser signals

- The laser calibration used between two cesium scans is a relative calibration with respect to a laser reference run. This reference run is recorded right after the latest cesium scan. The non- corrected gain variation is defined as follows:

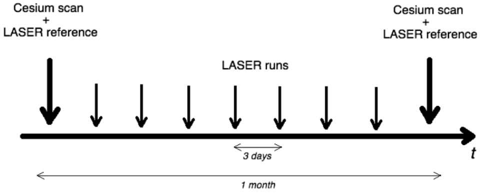
$$\Delta_i = \frac{R_i - R_i^{ref}}{R_i^{ref}} \tag{1}$$

  where i is a given TileCal channel, R_i is the normalized response of the channel i during the laser run close to the cesium scan

- The aim of Laser analysis is to correct the drifting channels of TileCal. This correction factor, f_{Laser}, is defined as:

$$f_{Laser} = 1/(1 + \Delta) \tag{2}$$

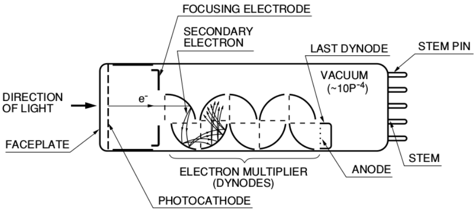
Comparing Cs and Laser Calibration



- Used to determine the precision and the systematics connected with the laser calibration constants.
- The two systems are expected to provide compatible measurements because the scintillator effect is negligible over the considered periods (typically one month).
- To compare the laser and the cesium calibration constants, pairs of the closest laser run/cesium scan are selected.

- For each pair of laser run/cesium scan, the ratio of laser calibration constants and cesium calibration constants (f_{Laser}/f_{Cesium}) is considered.
- The mean obtained by the fit quantifies the compatibility of the two calibration systems and is interpreted as the systematics on the laser calibration constants.
- The σ obtained by the fit can be interpreted as the statistical precision of the laser system assuming that the uncertainty on the cesium calibration constants is negligible with respect to the laser one.

PMT Gain Variation



- The PMT gain reduces during an increased dose of radiation (fatigued PMT) and then, it starts recovering in the absence of radiation, which is due to the reduction of secondary emissions from PMT dynode.
- Since this a random process, the gain variation shows a larger spread with increased radiation dosage.

Radiation Ageing of Scintillators and WLS Fibres

- Increased radiation dosage reduces the light yield and transparency of the scintillators and WLS dyes due to saturation of the molecular orbitals involved in fluorescence and phosphorescence.
- Due to this, the Cesium response is lesser than the Laser response and $f_{Laser}/f_{Cesium} < 1$, during the period of data taking.

Laser Study

Introduction

Laser Data : We use the laser calibration data for 1/3rd of the laser runs for the year 2015.

Goals :

- Study the average PMT gain drift of the different cell types
- Study the RMS of the variations in the channels (as done with Cesium)
- Study the difference between the measurements of the two PMTs connected to a given cell.

Laser runs in 2015

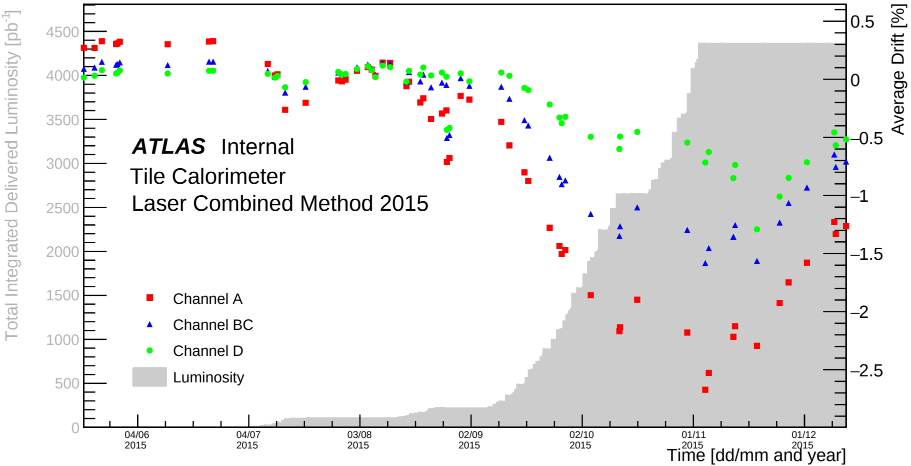


Figure: Average Drift vs Time

Laser runs in 2015

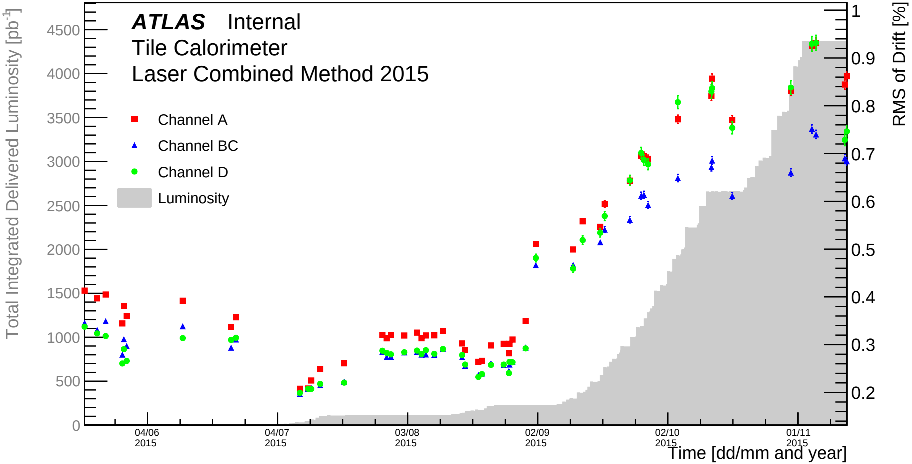


Figure: RMS of the Drift vs Time

Laser runs in 2015

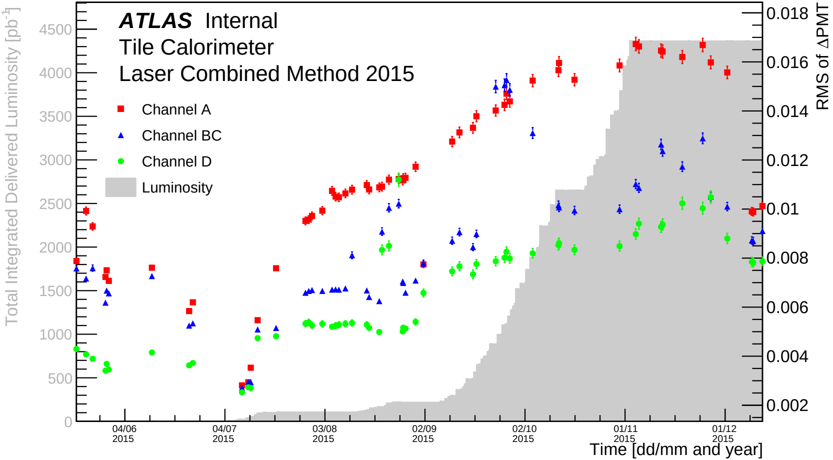


Figure: RMS of ΔPMT vs Time

Laser runs in 2015

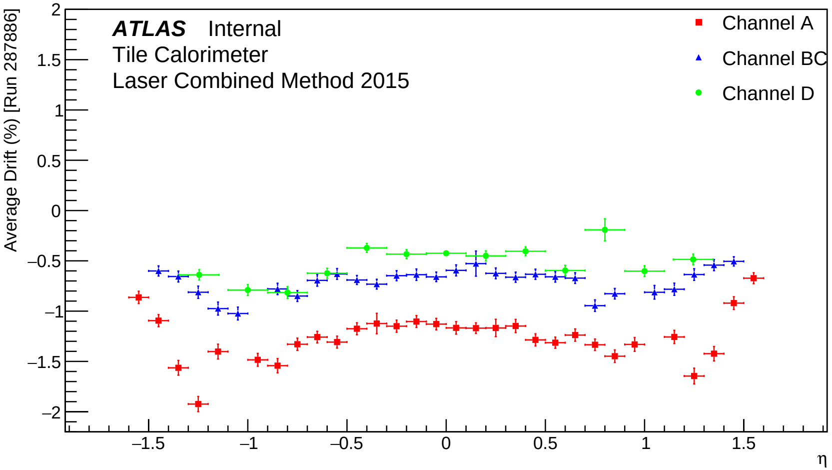


Figure: Average Drift vs η (Dec 12, 2015)

Laser runs in 2015

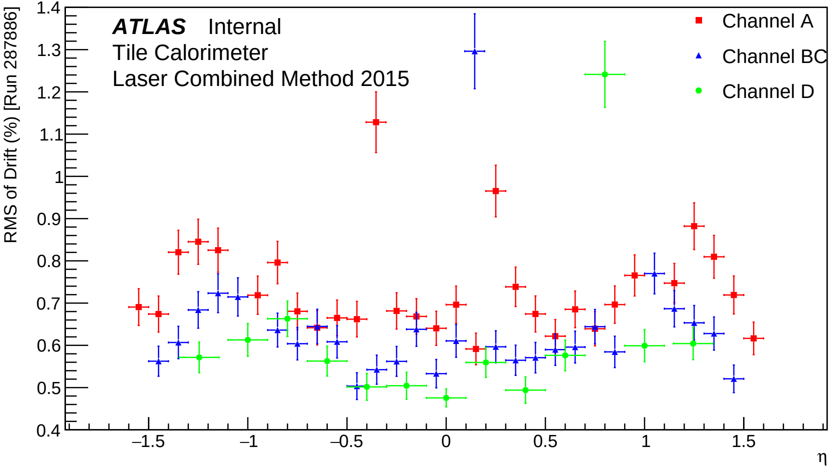
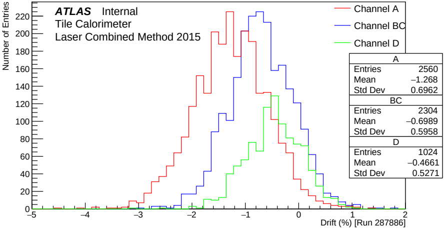
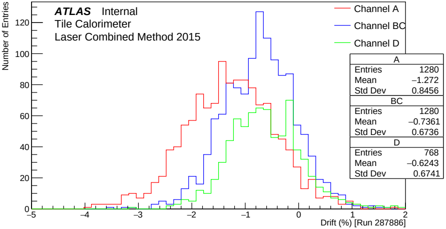


Figure: RMS of Drift vs η (Dec 12, 2015)

1-D Distributions for Laser runs in 2015



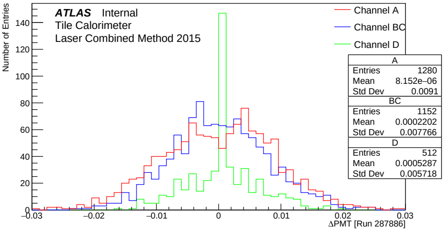
(a) Long Barrel



(b) Extended Barrel

Figure: Distribution of Drift (Dec 12, 2015)

1-D Distributions for Laser runs in 2015



(a) Long Barrel (b) Extended Barrel

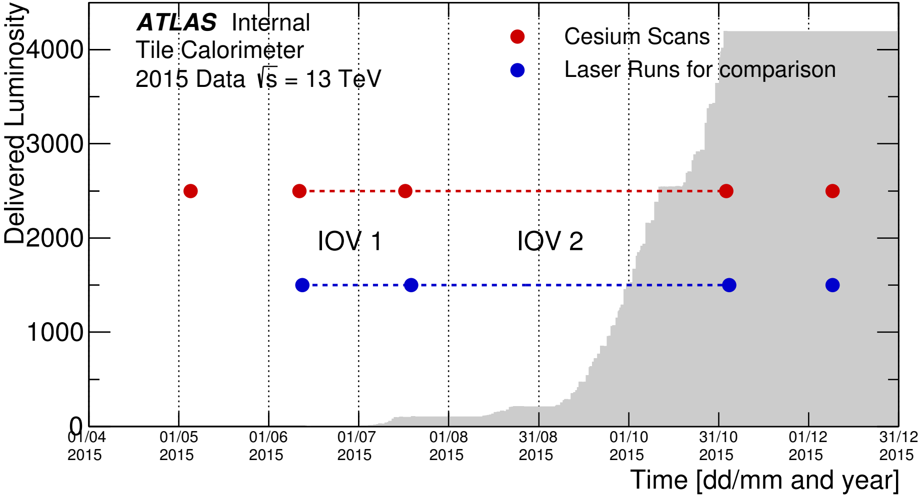
Figure: Distribution of ΔPMT (Dec 12, 2015)

Comparison against Cesium

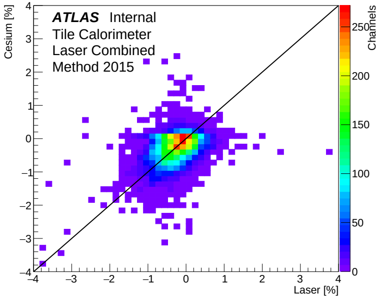
Introduction

- We start doing a comparison of data of the year 2015, where more scans were performed.
- Cesium data: Extracted Cesium constants from COOL DB.
- CESIUM (from DB, all with magnetic field)
  IOV1: 263962 (11/june) $\leftrightarrow$ 270000 (17/july)
  IOV2: 270000 (17/july) $\leftrightarrow$284600 (3/nov)
- LASER (new combined method)
  IOV1: 267534 (12/june) $\leftrightarrow$ 272493 (19/july)
  IOV2: 272493 (19/july) $\leftrightarrow$ 284682 (4/nov)

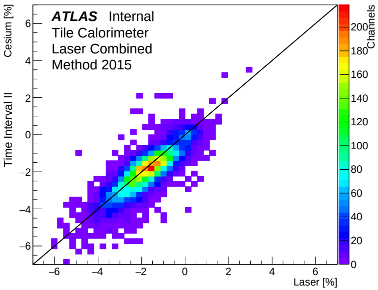
IOV's taken in the year 2015



Cesium vs Laser Scans in 2015



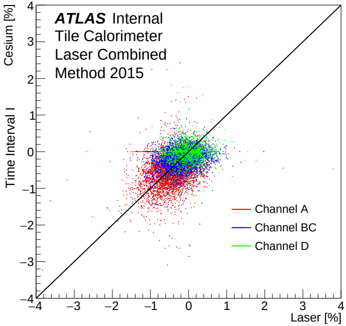
(a) IOV 1



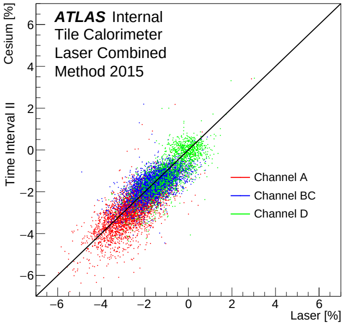
(b) IOV 2

Figure: Cesium vs Laser drift for all instrumented channels

Cesium vs Laser Scans in 2015



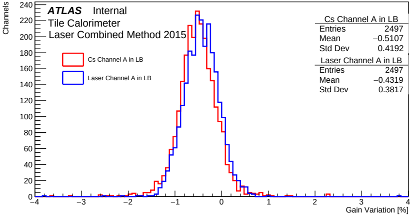
(a) IOV 1



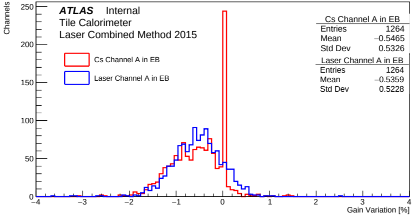
(b) IOV 2

Figure: Cesium vs Laser drift for different types of channels

Cesium vs Laser Scans in 2015

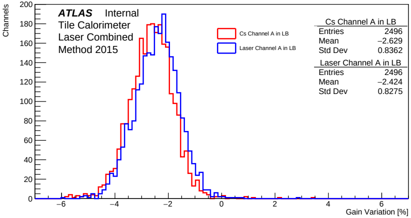


(a) Long Barrel

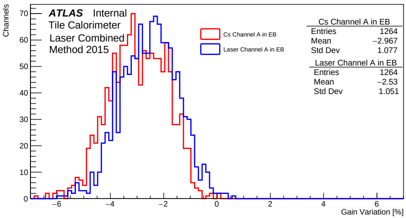


(b) Extended Barrel

Figure: Laser and Cesium gain variation for A channels IOV 1



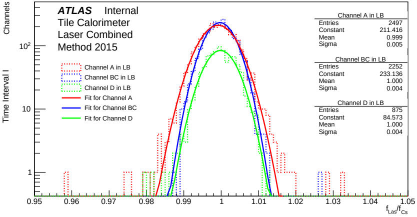
(a) Long Barrel



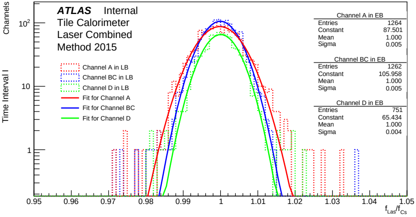
(b) Extended Barrel

Figure: Laser and Cesium gain variation for A channels IOV 2

Cesium vs Laser Scans in 2015

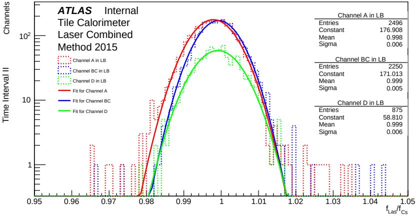


(a) Long Barrel

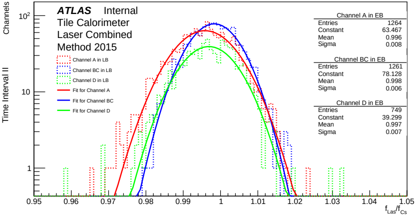


(b) Extended Barrel

Figure: Fraction of Laser and Cesium gain variation IOV 1



(a) Long Barrel



(b) Extended Barrel

Figure: Fraction of Laser and Cesium gain variation IOV 2

Fit Result

Table: Spread of the ratio f_{Las}/f_{Cs}, obtained by a Gaussian fit

Period IOV	**Barrel**	**Range of fit-width (%)** σ
1	Long barrel	0.3–0.4
1	Extended barrel	0.5–0.6
2	Long barrel	0.5–0.6
2	Extended barrel	0.6–0.7

Conclusion and Future Study

- This study will continue to include a comparison of Cesium –Laser for 2016 and 2017 (covering the full year).
- Due to the larger amount of delivered luminosities in these years, larger drifts in the response are expected.
- The ultimate goal of this study and future work is to extract conclusions from the comparison with Cesium measurements and approve some of the included plots for public use.

References

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- ATLAS Collaboration, *ATLAS tile calorimeter: Technical Design Report*, 1996, URL: `http://cds.cern.ch/record/331062`.
- ATLAS Collaboration, *Operation and performance of the ATLAS Tile Calorimeter in Run 1 (2018)*, arXiv:1806.02129
- ATLAS Collaboration, *The Laser calibration of the ATLAS Tile Calorimeter during the LHC run 1*, J. Abdallah et al JINST 11 (2016) T10005

Comments or Questions ?

Thank you for your attention!