Operational Experience with Radioactive Source Calibration of the CMS Hadron Endcap Calorimeter Wedges with Phase I Upgrade Electronics

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On Behalf of the CMS Collaboration

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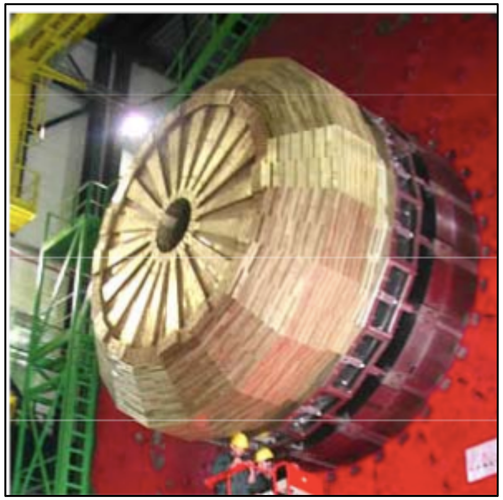
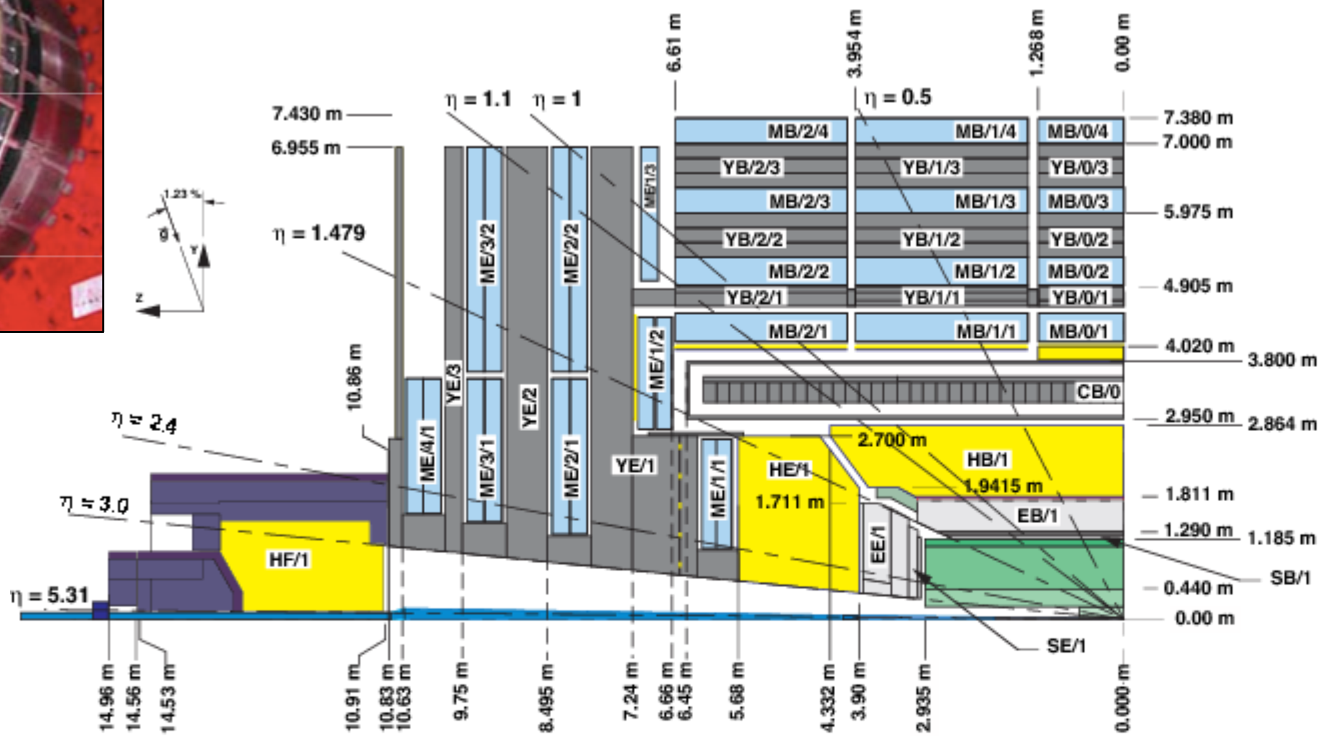
CMS Hadron Endcap (HE) Calorimeters





- Coverage $1.3<|\eta|<3$
- Inserted into the ends of 4T magnet
- Mounted on the iron endcap yoke

Hadron Endcap Details

HE is a sampling calorimeter with

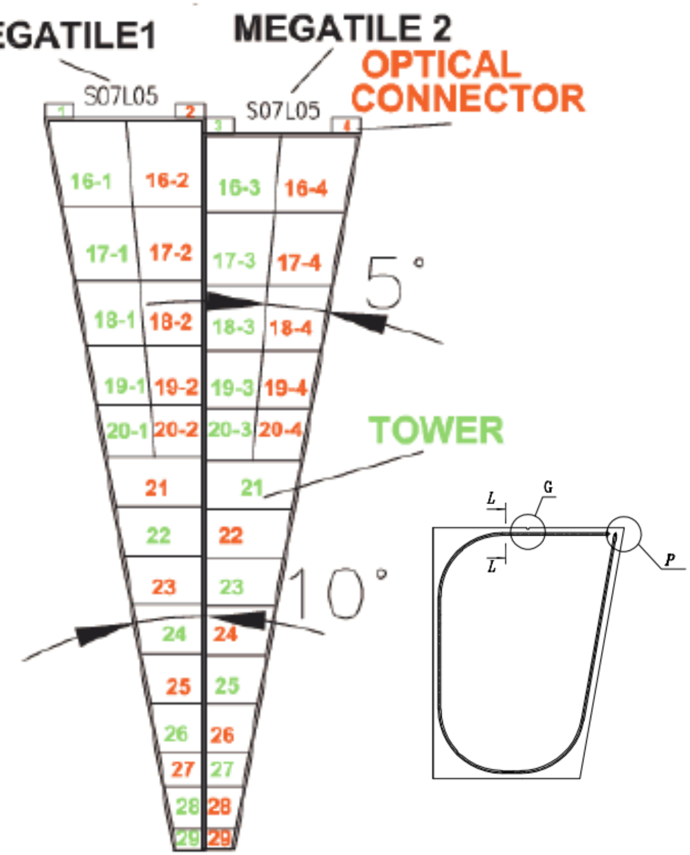
- Brass absorber (~ 8 cm each layer)

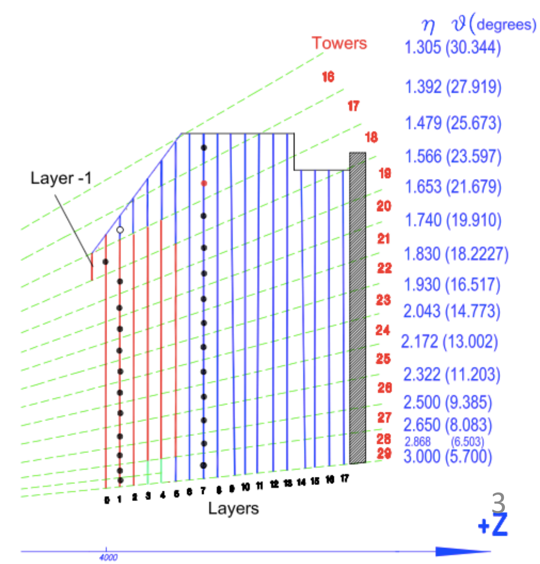
- Megatiles of scintillator tiles (4 mm SCSN81, 9 mm Bicron BC408 (for layer 0))

Light emission from tiles: λ=410-425 nm

Signal collected with wavelength shifting (WLS) fibers (λ=490 nm)

Photodetectors are hybrid photodiodes (HPDs)



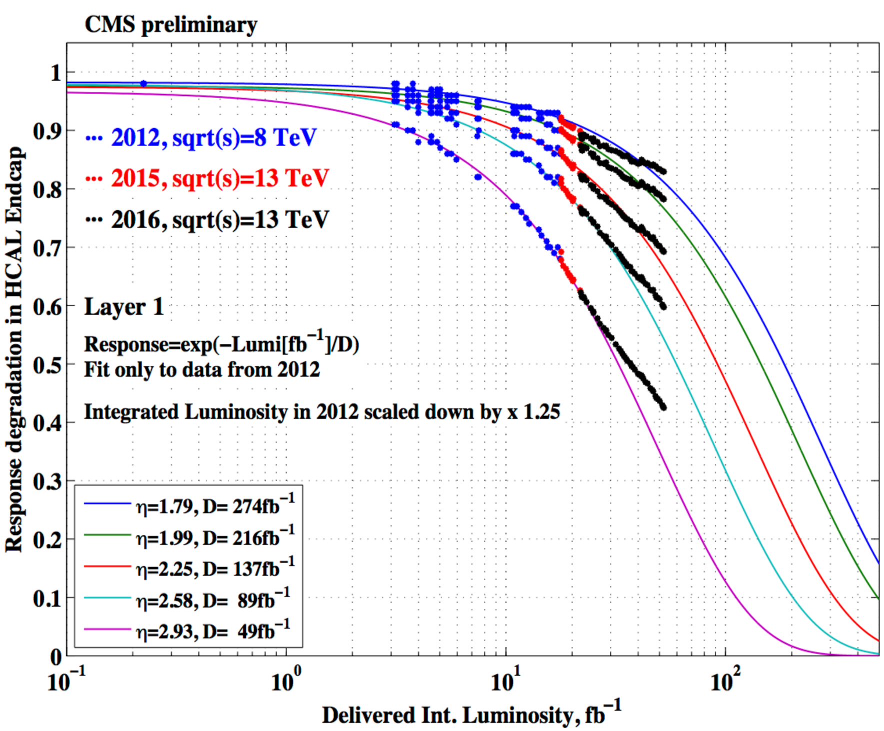


CMS NOTE-2008/010

Need for an HE Phase I Upgrade

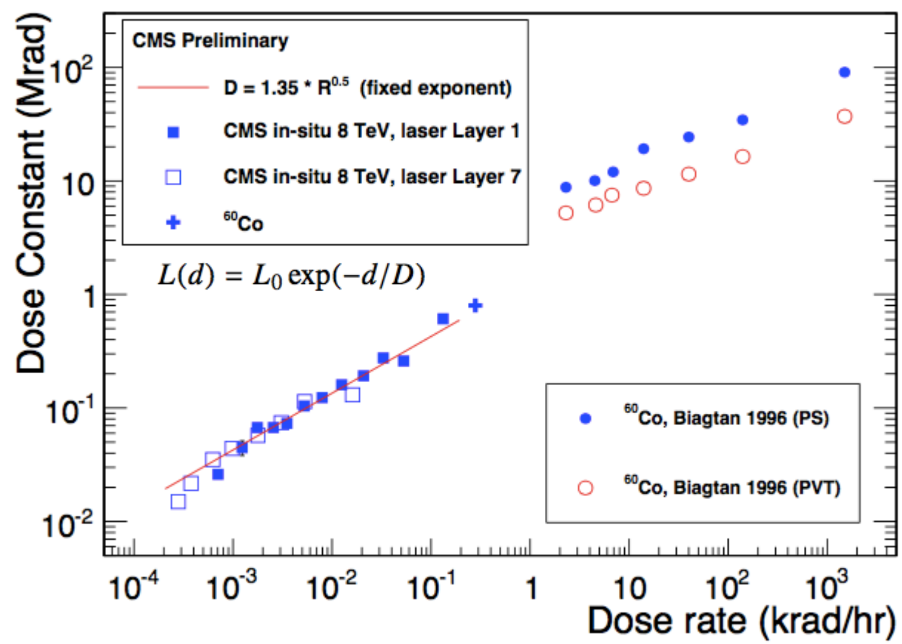
HE signal loss at various eta values as a function of integrated luminosity

- Measured with HCAL Laser system in layer-1 (also for layer-7) in 2012, 2015, 2016
- Fits are made to 2012 data only
- Signal loss due to radiation damage has slowed down (per unit of integrated luminosity) in 2016 with respect to fit to 2012 data



The dependence of the radiation damage on the rate at which the radiation dose is delivered is well (re-) established

- Damage <u>per unit of delivered dose</u> is lower for higher dose rate
- Also confirmed by in-situ data using HCAL laser monitoring system



JINST 11, T10004, 2016

HE Phase I Upgrade

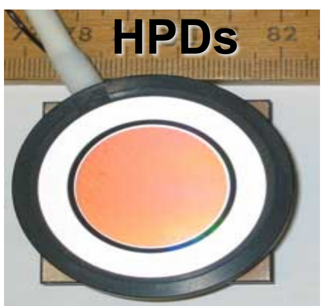
New, improved photo-detectors

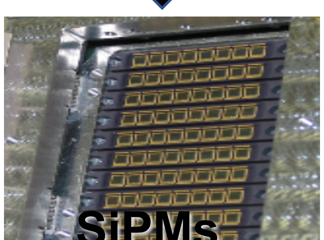
- Hybrid Photo-Diodes (HPD) → Silicon Photo-Multipliers (**SiPM**)
  - eliminate high amplitude noise and drifting response of HPDs
  - mitigate effects of radiation damage to scintillators and WLS fibers
  - allow to increase the longitudinal segmentation of readout (pile-up suppression and recalibration of depth-dependent aging)

New front-end electronics – support of increased number of channels and new photodetectors

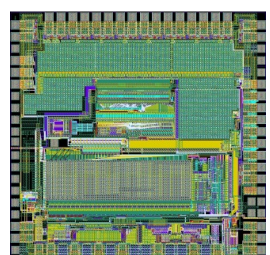
- QIE8 (7-bit ADC) ➔ **QIE11** (8-bit ADC, embedded **TDC**)

New back-end electronics (μTCA) - supports larger data volumes, new trigger primitives



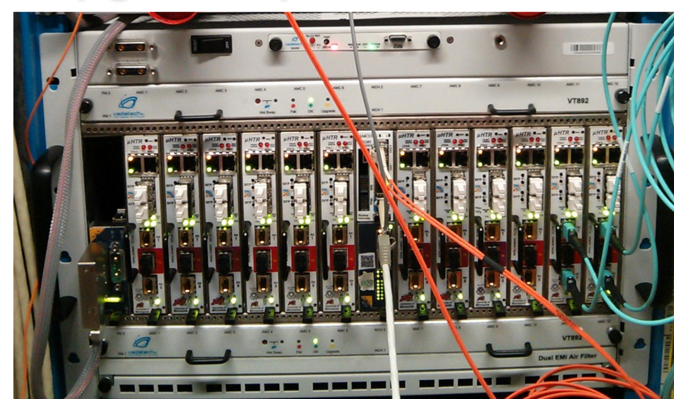


QIE11



(already installed)

Upgraded μTCA Back-end



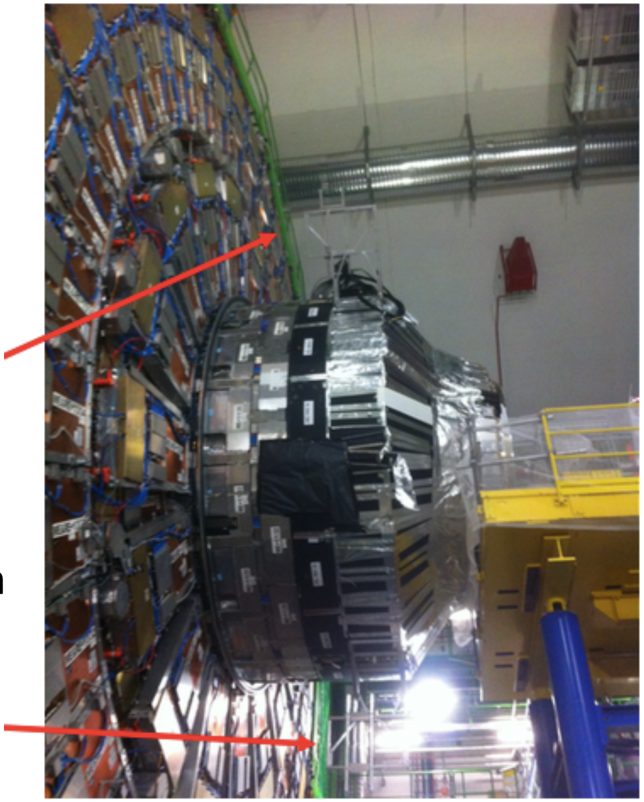
Calibration of HE with Radioactive Source

Necessary to:

- Establish calibrations at the per tile level
- Identify potential issues in the optical paths
- Validate the installation of the Phase I Upgrade in Year End Technical Stop 2017-18.

Entire HE source calibration operations were completed in 8 weeks during Extended Year End Technical Stop 2016-2017 with Phase 0 electronics (+ 1 wedge with Phase I electronics)!

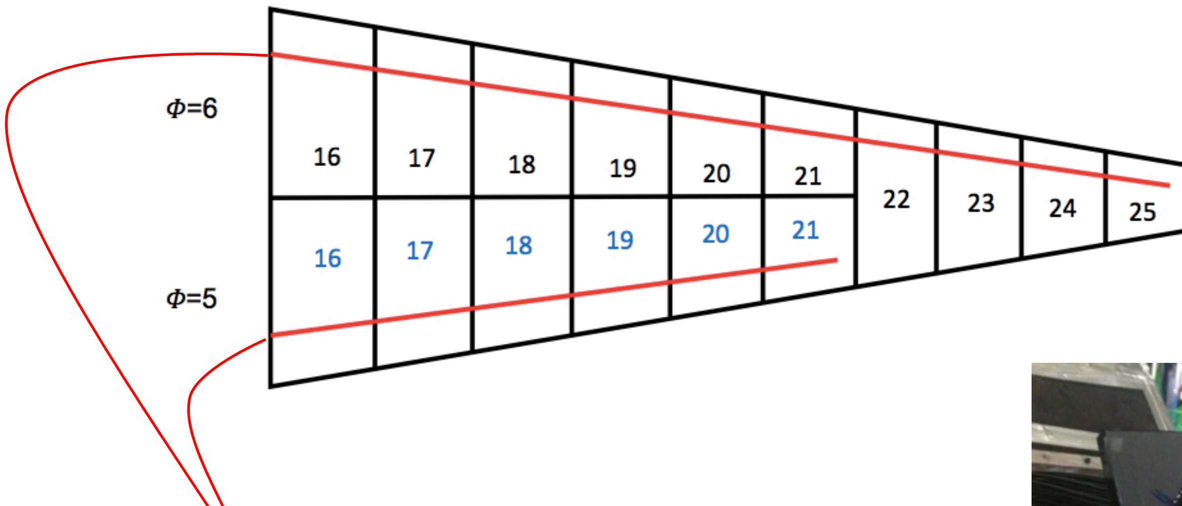
Source driver locations: 2 (not shown), 6 and 10 o'clock positions as seen from the IP



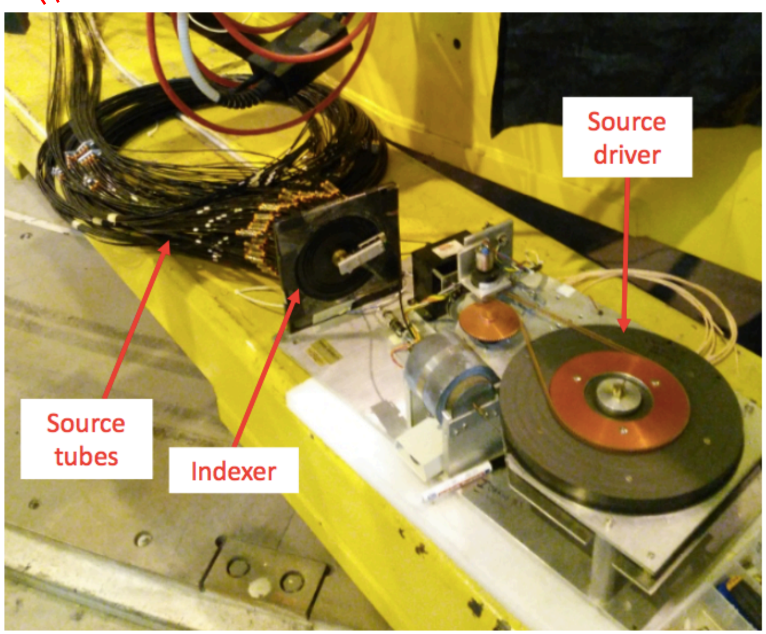
^{60}Co Sourcing Exercise with Phase I Electronics

- Was performed in October 2016 in the H2 test beam area at CERN with Phase I Upgrade electronics.
- Used 1 megatile (2 ϕ sectors).
- Investigated the source response and its dependence on source wire speeds and calibration effects.
- Was the first validation of the HE Phase I sourcing operations.

Source Driver and the Test Megatile

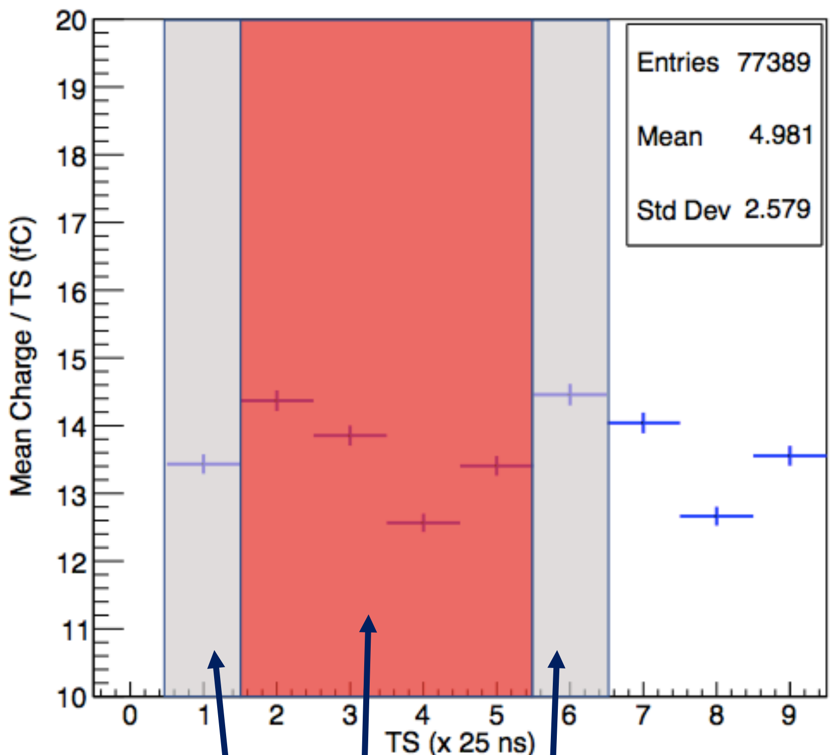


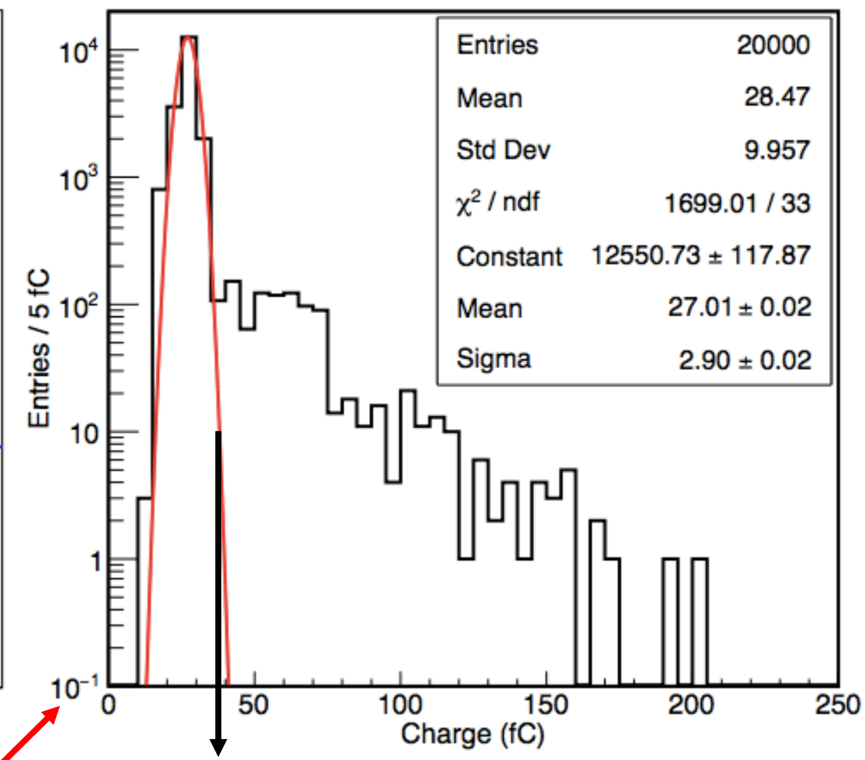
Numbers are η indices



Calibration of the SiPMs

Use dedicated pedestal runs to calibrate the SiPMs: Randomly triggered events with 10 consecutive time samples of 25 ns each.





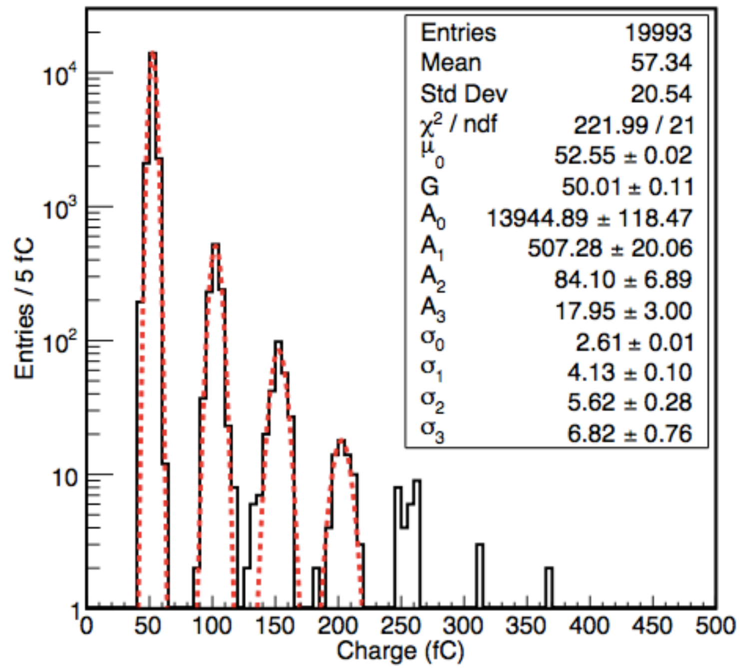
Integration window

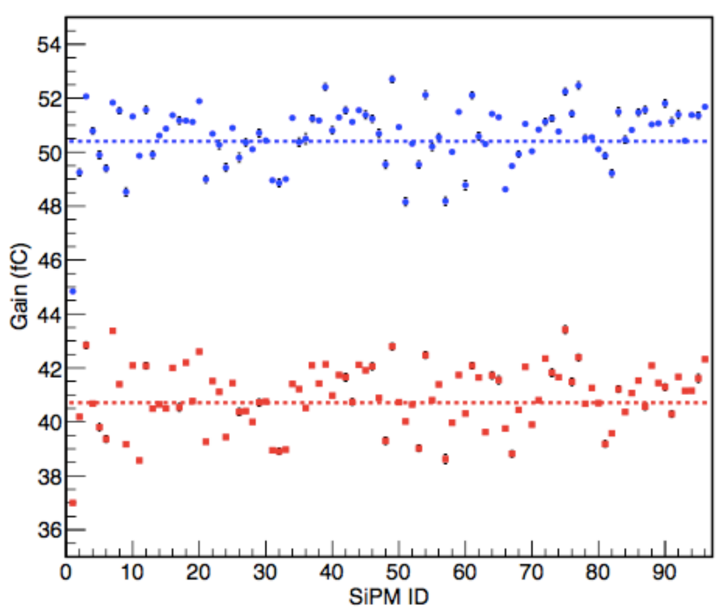
Transients window

Find the point where the fit falls by three orders of magnitude

Identify an integration window for each channel for each event

Calibration of the SiPMs





Single fit function for the entire spectrum down to three orders of magnitude drop of the peak.

Cross-talk is not tried to be described.

$$f(x) = \sum_{i=0}^{N_{peaks}-1} A_i e^{-\frac{1}{2}\left(\frac{x-\mu_i}{\sigma_i}\right)^2}$$

$$\mu_i = \mu_0 + iG$$

SiPM gain is a direct parameter of the fit.

Simple calibration tool for large scale SiPM readout.

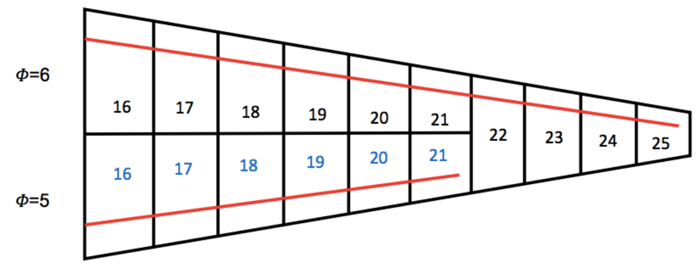
Sourcing Data Analysis Procedure

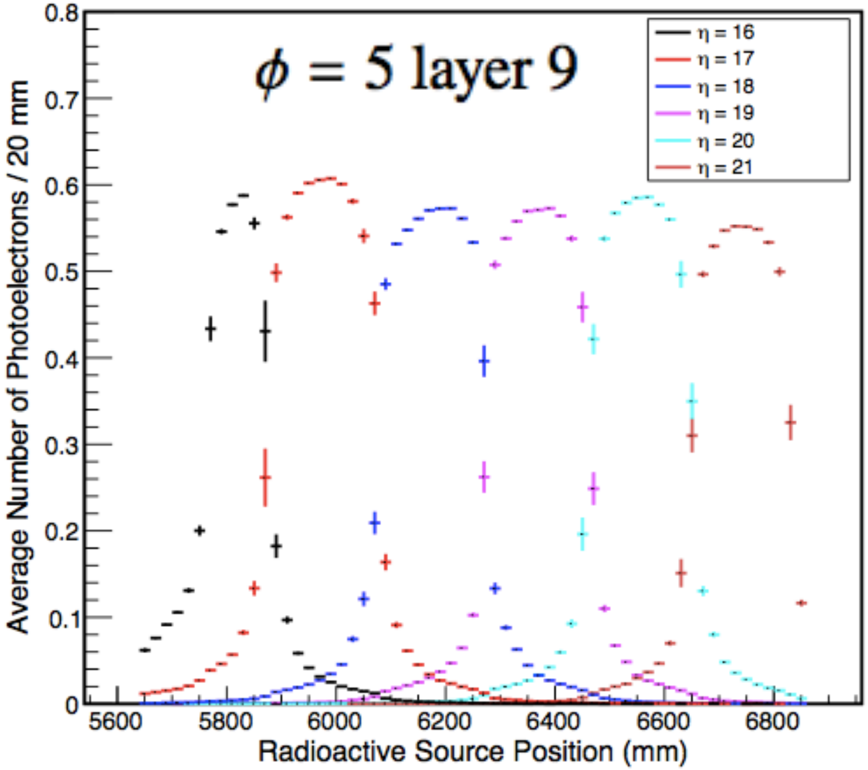
Radioactive source calibration data is:

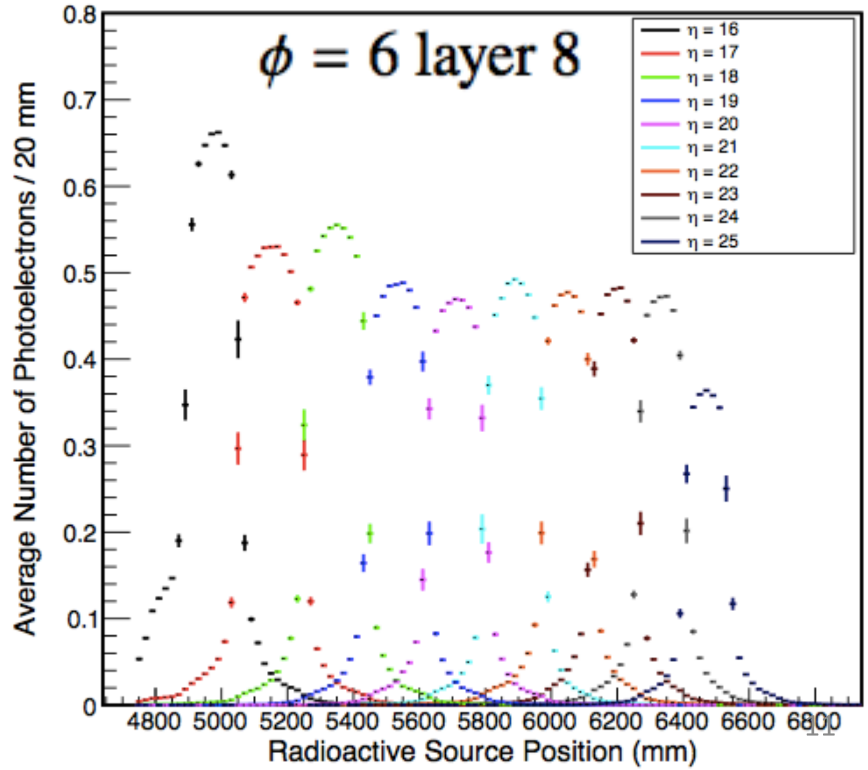
- a set of periodically recorded histograms of SiPM signals (sampled every 25 ns in units of ADC counts recorded by QIE11 front-ends – then converted into units of photoelectrons using the SiPM calibrations)

  +

- source position inside the megatile.







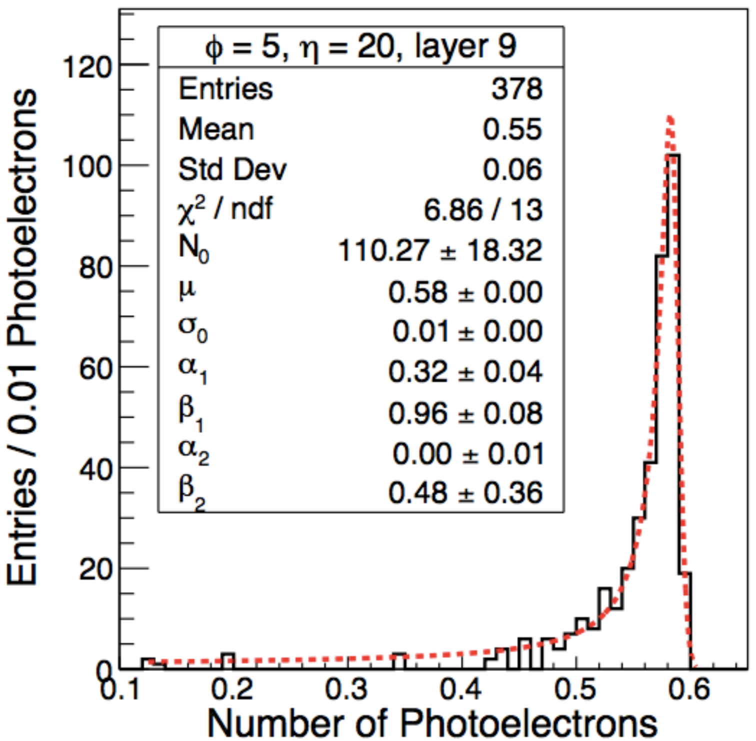
Sourcing Data Analysis Procedure

The photoelectron spectra (zero suppressed at 0.07 pe) is fit to a Gaussian with variable width.

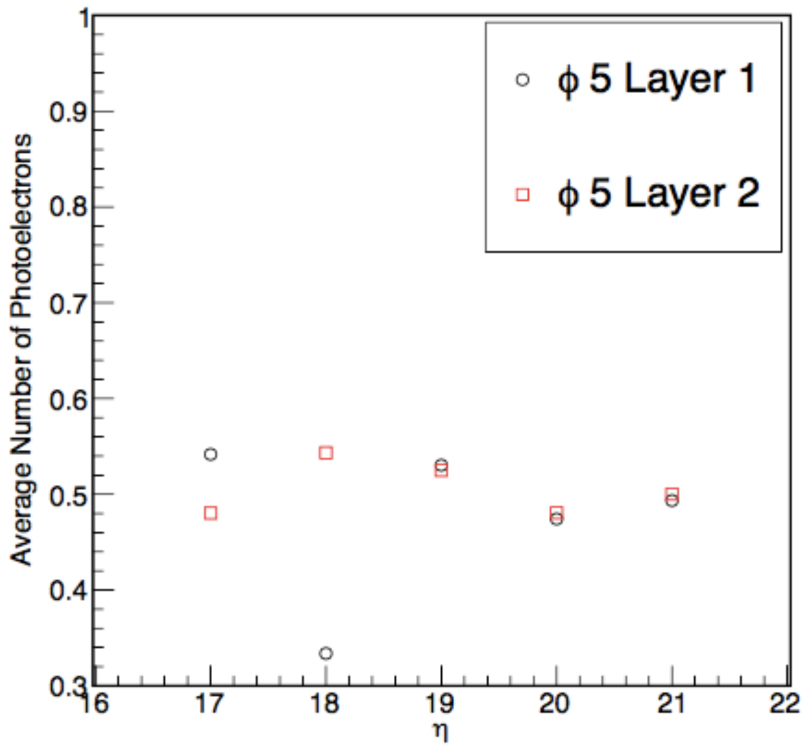
$$f(x) = N_0 e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma(x)}\right)^2}$$

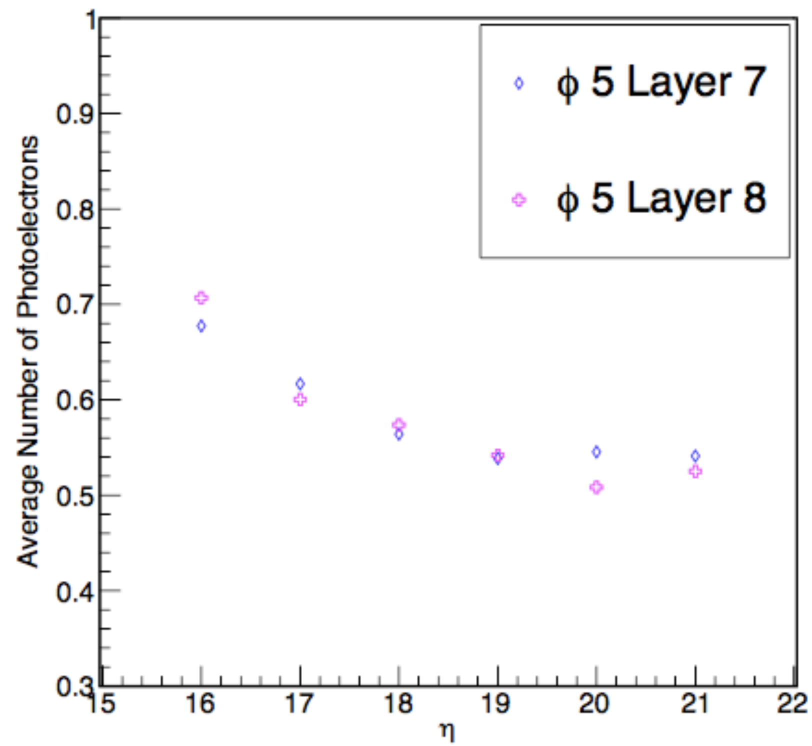
$$\sigma(x) = \sigma_0 + \alpha_1(\mu - x)^{\beta_1} \qquad \text{for } x < \mu$$

$$\sigma(x) = \sigma_0 + \alpha_2(x - \mu)^{\beta_2} \qquad \text{for } x \geq \mu$$



Source Response within the Same Calorimeter Tower

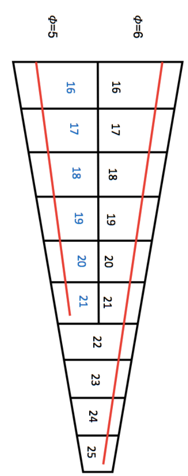




Layers 1 and 2 are the most upstream layers

➔ several interventions in the past 10 years

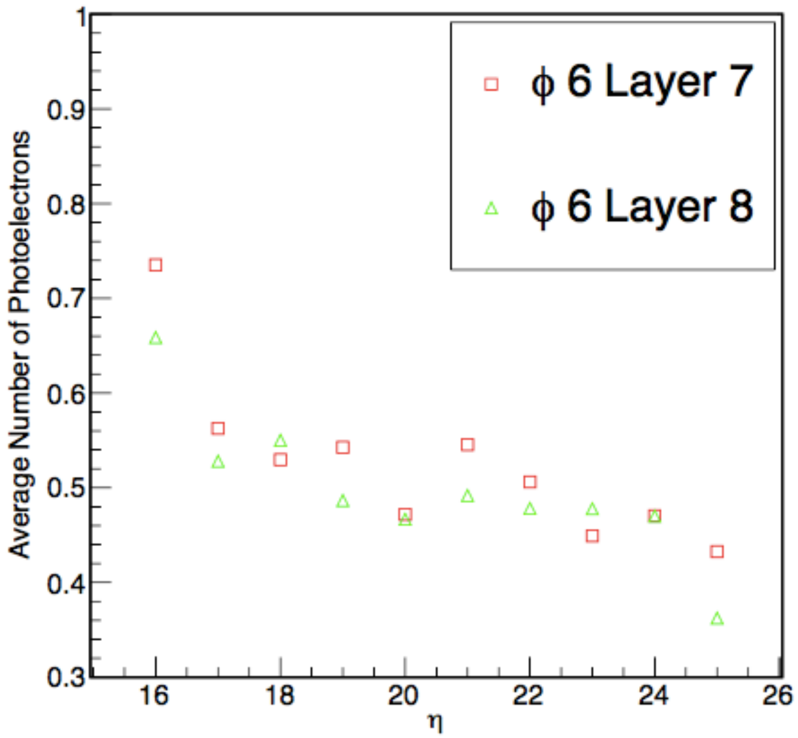
➔ possible degradation of the optical path

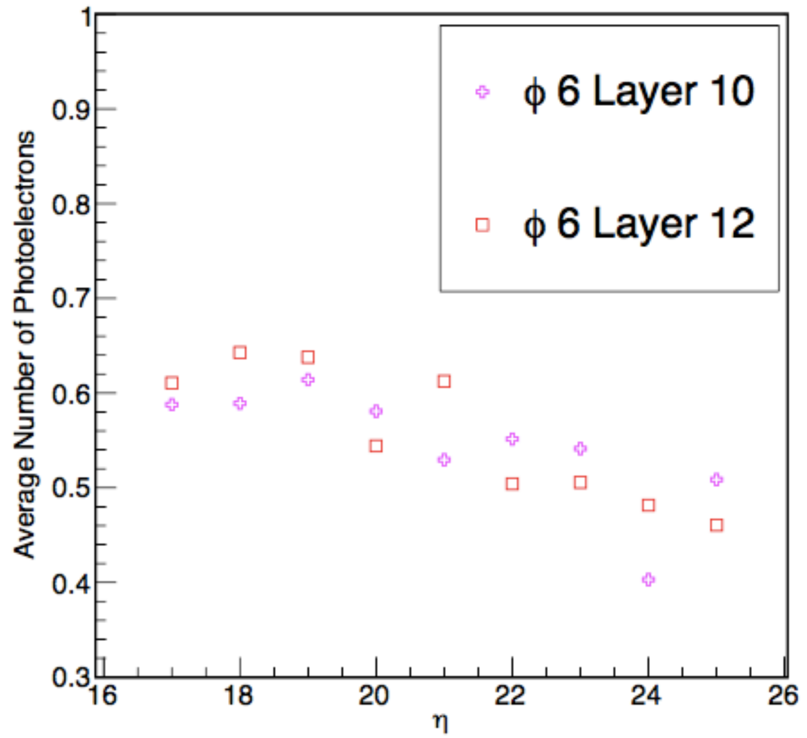


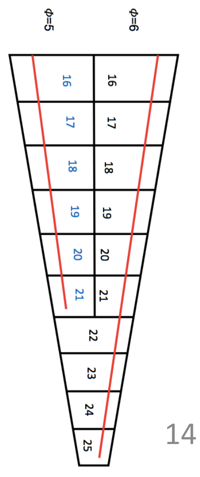
Response within expectations

Demonstrates the decreasing tile size with increasing η

Source Response within the Same Calorimeter Tower



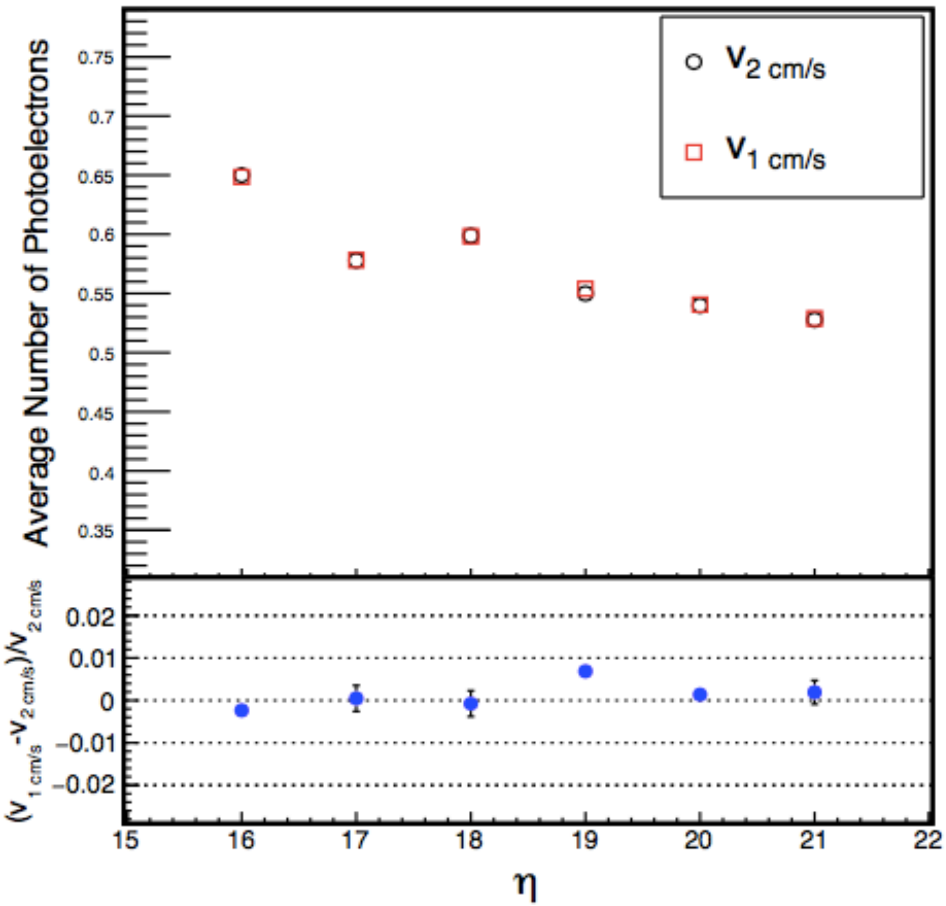




Up to 15 % variation between the responses of tiles from different layers (except a few outliers).

Dependence of the Source Response on the Source Speed

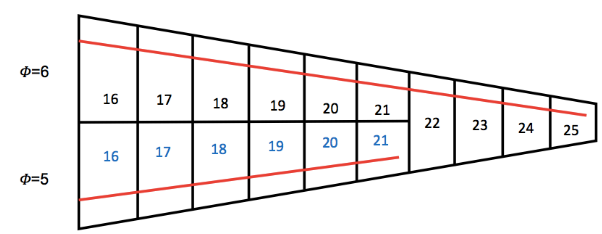
$\phi = 5$ sector tiles at layer 6



With lower source speeds:

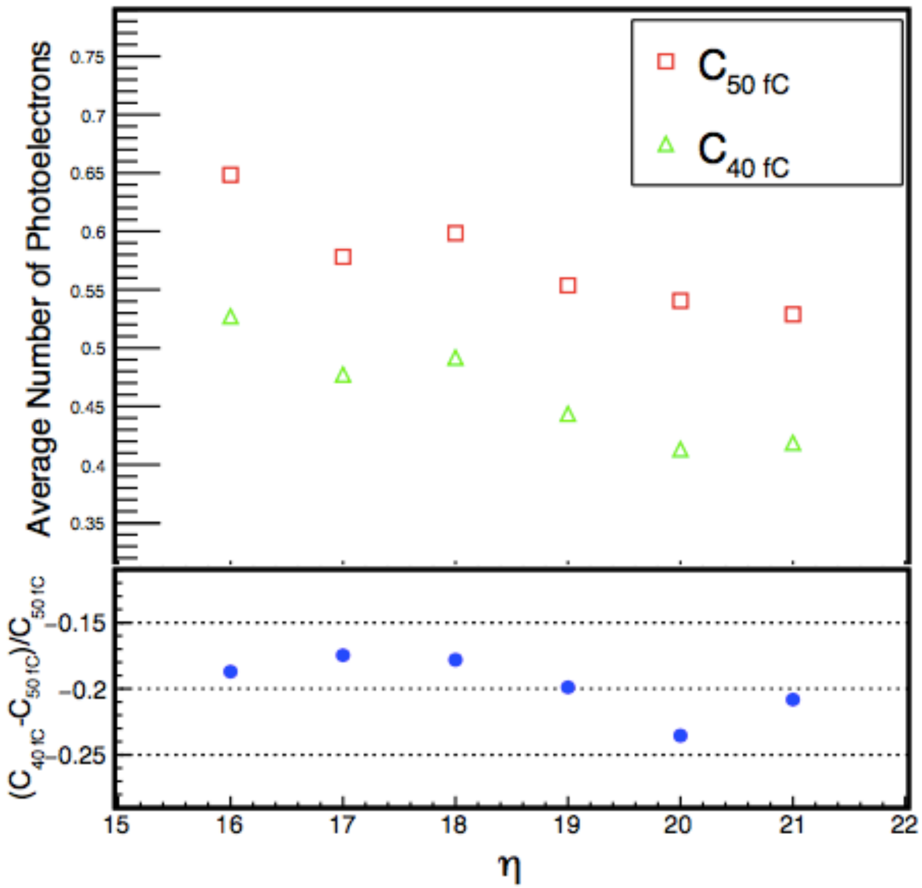
- Increased statistics in the photoelectron spectra hence higher quality fits.
- Final results are not affected.

Higher speeds are preferable for the actual sourcing campaigns.



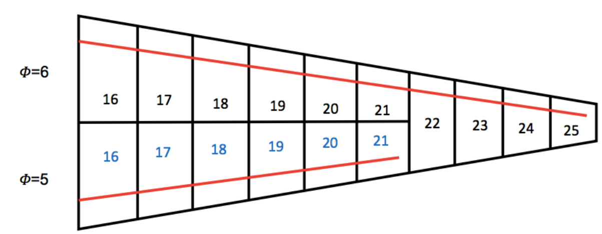
Dependence of the Source Response on the SiPM Calibration

ϕ = 5 sector tiles at layer 6



Two sets of gains: 50 fC (default) and 40 fC

The 20 % decrease in the gain is observed as the average drop of the source response by 20 %.



Conclusions

- Sourcing operations of HE with Phase I electronics was validated months before the actual HE sourcing campaign performed during EYETS 16-17 with Phase 0 electronics, also with Phase I electronics for 1 wedge.

- The exercise allowed us to estimate the time and effort needed for the actual sourcing campaign.

- Prompt analyses were developed during the exercise and were successfully utilized during the actual sourcing campaign.

- Various techniques were developed in the analysis of the data.

For the sourcing campaign of HE with Phase I electronics in 2018:

  - The procedure was established.

  - Necessary tools were developed.