HCAL electromagnetic analysis and MC digitization

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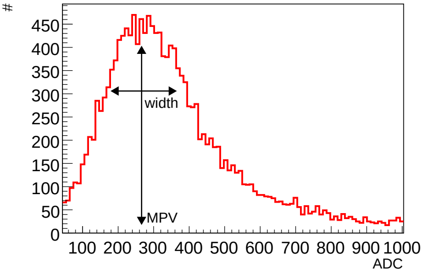
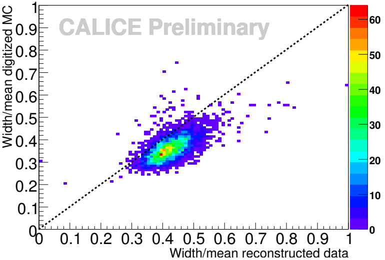
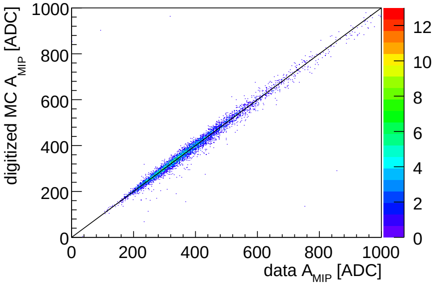
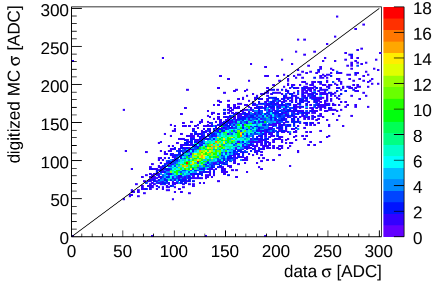
- Muons as minimal ionizing particles used to equalize cells $\rightarrow$ most probable value (MPV) of fit to energy spectrum $\widehat{=}$ MIP calibration constant (A_{MIP})
- Small energy scale $\rightarrow$ not effected by saturation effects
- Threshold cut defined by 0.5 MIP $\rightarrow$ important to reproduce correct width in digitized MC



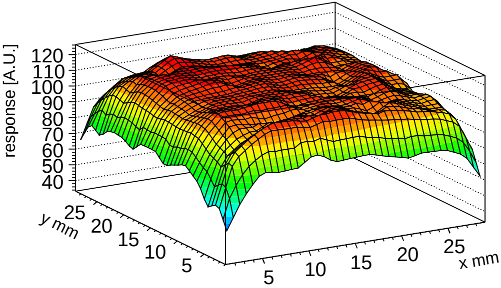


- Digitization: conversion from energy deposited (MPV $\widehat{=}$ 861 keV) to ADC
- Including Poissonian pixel statistic (number of SiPM pixels firing fluctuates for same amount of light) and adding of noise (random trigger events)
- MPV and width are determined for data and digitized MC in the same way
- MPV correct (lookup of A_{MIP}), but width of energy spectrum too small



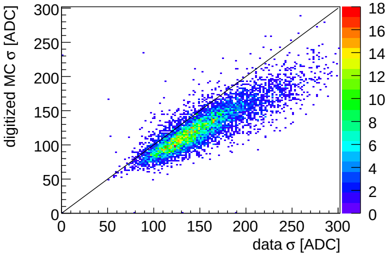


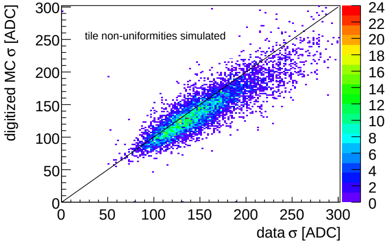
- Possible reason for smaller width in digitized MC: response of single tile not uniform
- Not included in raw MC
- Plot shows response of 3x3cm^2 tile (mean 100); position from single-tile test-bench scan
- Largest response in the middle ($\approx$ 110) decreasing at the borders ($\approx$ 80)



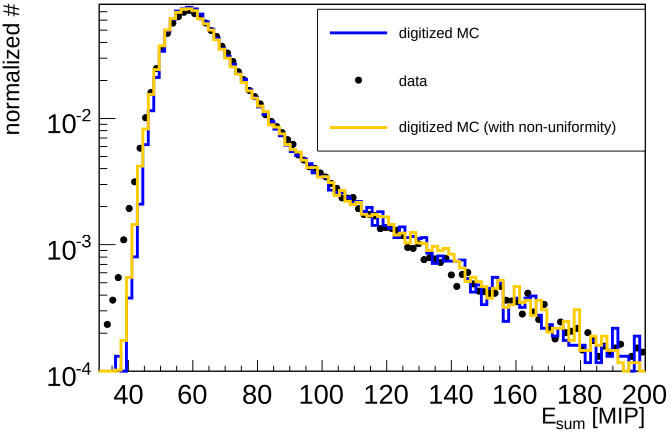
(ITEP private communications)

- First test in digitized MC: multiply randomly picked response factor to energy deposited by muon

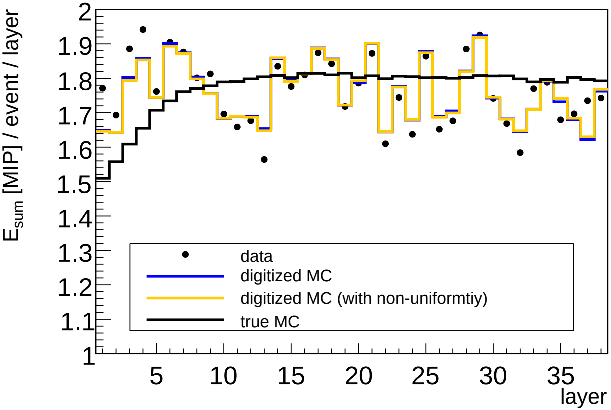




- Correlation of width without (left) and with tile non-uniformity simulated (right)
- Agreement of width data / digitized MC improved significantly

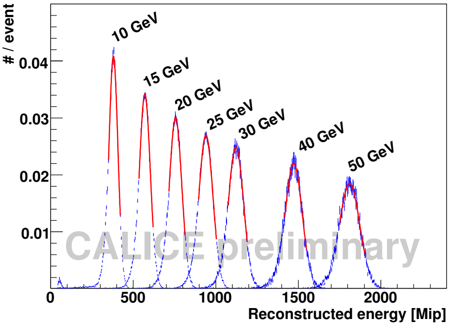


- Energy sum well described by digitized MC
- Tile non-uniformities included give slightly better agreement in low energy region



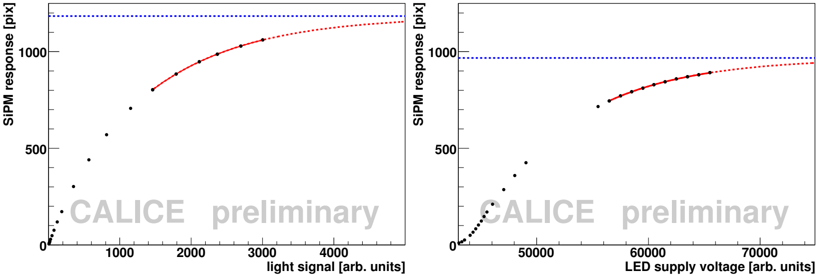
- Longitudinal profile shows need for digitization best
- Single module features like dead or noisy cells result in large divergence from true MC
- No advantage simulating tile non-uniformity

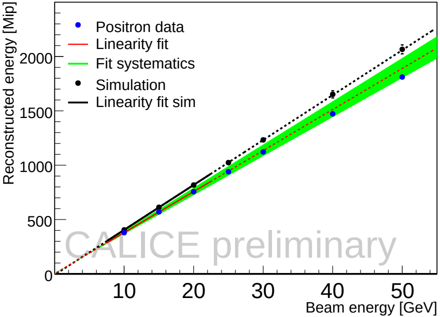
- Digitization validated with response to muons $\rightarrow$ low energy scale understood
- High energy scale comes with the need for saturation correction of SiPM response
- Best way to test is the response to electromagnetic showers
- Positrons runs (2007 CERN) are used ranging from 10 GeV to 50 GeV
- For digitization **no** tile non-uniformity will be simulated



(Positron data)

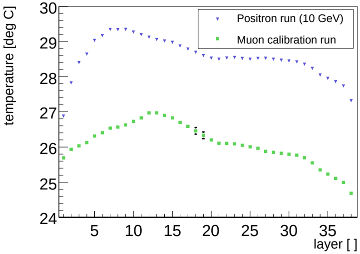
- Studies on the in-situ response curves with the LED system indicate that mounted SiPMs saturate at lower signals than unmounted
- Geometrical mis-alignment of the wavelength shifting fiber w.r.t. to the SiPM reduces effective number of pixels
- For reconstruction: original curves measured by ITEP are 80% scaled for all SiPMs



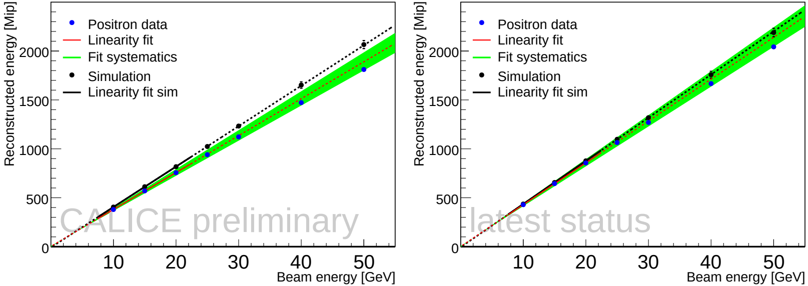


- Data reconstructed with scaled response curves
- Digitized MC includes noise, optical crosstalk (light leaking to adjacent, 10%), pixel statistic and saturation simulation
- Reconstruction of data / digitized MC is identical
- Energy sum shows difference data / digitized MC up to $\approx$ 17%

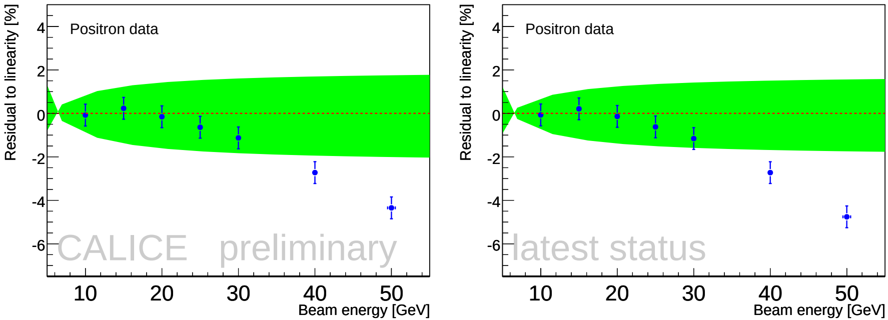
- Missing so far, temperature correction of calibration constants
- $\frac{1}{A_{MIP}} \frac{dA_{MIP}}{dT} = (-3.8 \pm 1.4) \frac{\%}{K}$
- $\frac{1}{Gain} \frac{dGain}{dT} = (-1.7 \pm 0.4) \frac{\%}{K}$
- Positron runs recorded at $\approx$ 2.5° C higher temperature than muon runs that were used for calibration
- Gain (ADC / pix) calibration is averaged over the whole test-beam period and has a mean temperature of 27°C



- $\rightarrow$ Correct calibration constants according to temperature differences

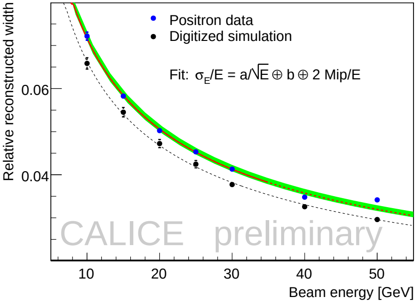


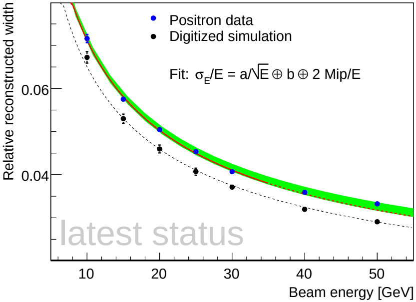
- MIP constants are corrected for module wise temperature differences w. r. t. muon calibration runs
- $\Rightarrow$ smaller MIP constants result in more visible energy [MIP]
- Discrepancy data / digitized MC reduced by 10% percentage points

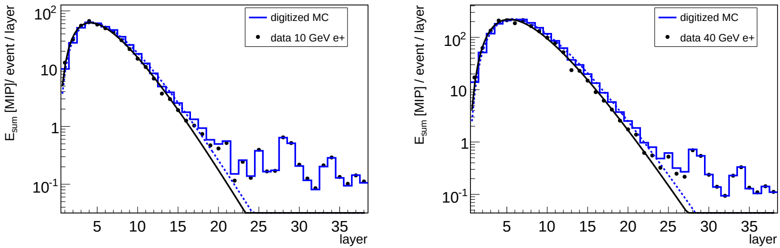


- Gain constants are corrected using an averaged temperature over the whole calorimeter, positron runs $\approx 1.7^{\circ}$C hotter than calibration average
- No improvement is observed for the residual to linearity

- Relative width of the reconstructed energy as a function of beam energy
- data: a = 22.1%, digitized MC: 20.4%, for both b is compatible with zero
- Uncertainty on calibration constants not reflected in digitized MC, it uses very same for digitization and calibration
- Tile non-uniformities need to be modeled in the generation of the MC itself

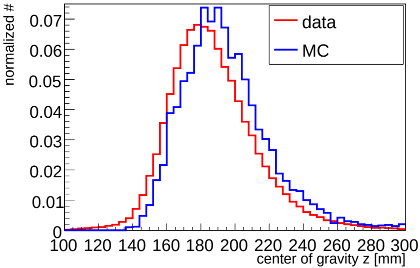


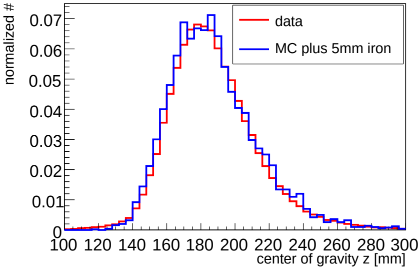




- 10 GeV (left plot) shower maximum data: 4.14 layer, digitized MC: 4.45 layer
- 40 GeV (right plot) shower maximum data: 5.31 layer, digitized MC: 5.72 layer
- Shower shape in good agreement, but seems to start earlier in data $\rightarrow$ hint for missing material in MC

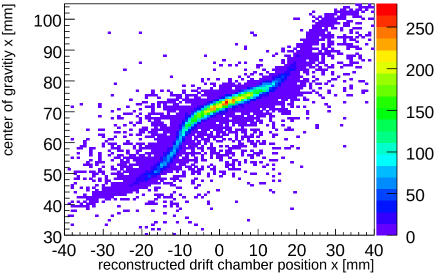
- That the shower is starting earlier in data can also be expressed in terms of the center of gravity (energy weighted position of hits) in z
- Additional material was put in front of the calorimeter to study the impact on the shower (implementation in a GEANT3 model of the AHCAL)
- It was found that the amount of $\approx$ 5 mm iron are needed to match MC and data

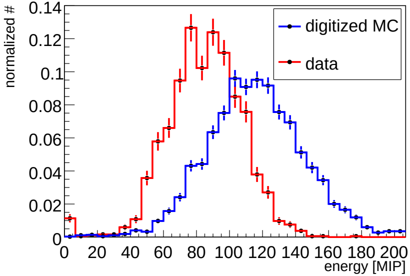




(Study by Sergey Morozov)

- To understand discrepancies, single cell analysis started
- Saturation behaviour can be seen best in shower core
- ⇒ Select only events with primary particle hitting center of a tile
- Center of gravity is used to align drift chambers and calorimeter
- Quality of single cell agreement differing
- ⇒ Temperature and scaling corrections need to be applied on the single cell level





(single cell in shower core)

Conclusion:

- Digitization validated with muons and positrons
- Single cell features reproduced $\rightarrow$ width of MIP response in good agreement if considering tile non-uniformity
- Proof of principle temperature correction of calibration constants $\rightarrow$ improvement expected using single cell temperature slopes of constants
- Positron data shows non-linearity not present in MC $\rightarrow$ further investigation of the saturation curve needed; single cell scaling factors coming
- Shower shape well described $\rightarrow$ comparison of digitized MC for different hadronic shower models for 2007 pion data started