Validation of Geant4 simulation and digitisation of a SiPM-on-tile system

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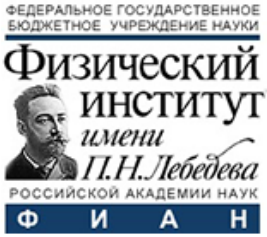
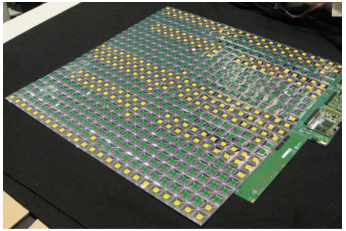
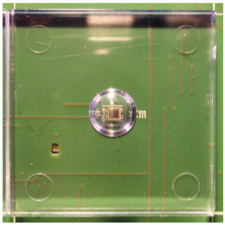


Motivation

Highly granular calorimeters

- Main trend in calorimetry for future collider experiments is inspired by Particle Flow applications and requirements of high precision measurements
- CALICE scintillator-SiPM hadron calorimeter for ILC, CLIC, FCC, CEPC, etc.
  - first physics prototype 2006-2012 (tiles with wavelenght-shifting fiber, 38 planes, ∼8000 tiles)
  - **new technological prototype from tiles with direct readout by SiPM (38 planes, ∼22000 tiles)**





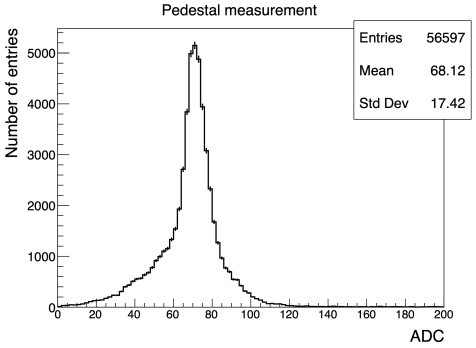
Simulations of detector response

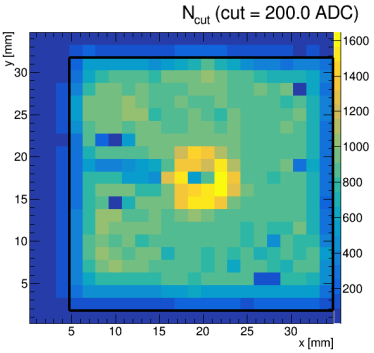
- detector development and optimisation are based on simulations
- photodetection properties are not simulated, are taken into account in digitisation
- **understanding of single detector element response is necessary for realistic digitisation**

Measurement conditions

Experimental setup and conditions

- CALICE tile 30 x 30 x 3 mm^3 with dimple BC-408 wrapped in foil
- electrons from ^{90}Sr as mips with normal incidence onto big tile surface
- KETEK SiPM 2.2 x 2.2 mm^2 (12k pixel) gain = 14.8 ADC (or 23.1 ADC)
- automatic scan with step 1.5 mm over a bit larger area than 30 x 30 mm^2 tile
- LED measurements
- pedestal measurements
- temperature within $\pm 2^oC$
- trigger tile placed below measured tile

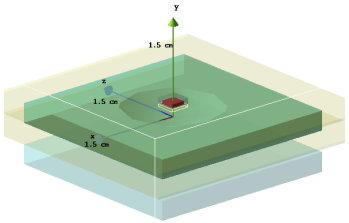




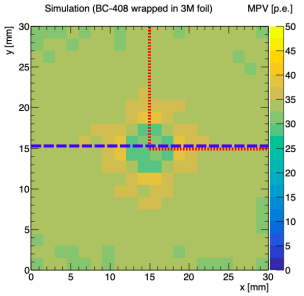
Simulation conditions

Geometry and material properties

- CALICE tile 30 x 30 x 3 mm^3 with dimple (green) wrapped in foil (not shown)
- tail of electron spectrum from ^{90}Sr 1.8–2.28 MeV, normal incidence wrt big surface
- SiPM box and active window 2.2 x 2.2 mm^2 signal = number of photons in SiPM window
- trigger tile under the measured tile (light blue)
- scintillator with 10 photons/keV
- refraction index 1.58
- **attenuation length 0.6 m** (bulk att.length from manufacturer ∼2 m)
- energy distribution of scintillation photons
- energy dependence of foil reflection index
- one quarter of scan surface simulated



dimple not in scale, foil not shown

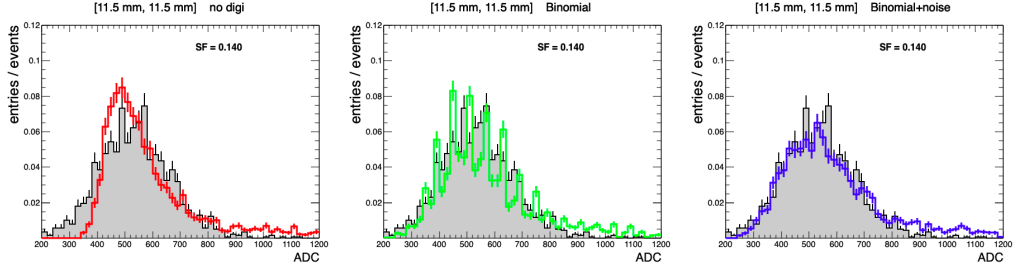


- **simulated quarter**
- 3 times reflected with random digi
- **scan line for attenuation studies**

Digitisation of simulation

Digitisation of simulated signal using PDE (0.14—0.16) as a single scale factor (SF)

- **pure signal**[ADC] = **NumberOfPhotons*SiPMGain*PDE**
- **noise**[ADC] sampled from **Gaus(mean$_{ped}$, σ_{ped})**
- **digitised signal**[ADC] sampled from **SiPMGain*Binomial(NumberOfPhotons,PDE)+noise**
- **parameters from data**: mean$_{ped}$=36 ADC, σ_{ped}=10 ADC, SiPMGain=14.8 ADC



Digitisation helps to improve agreement between data and simulations.

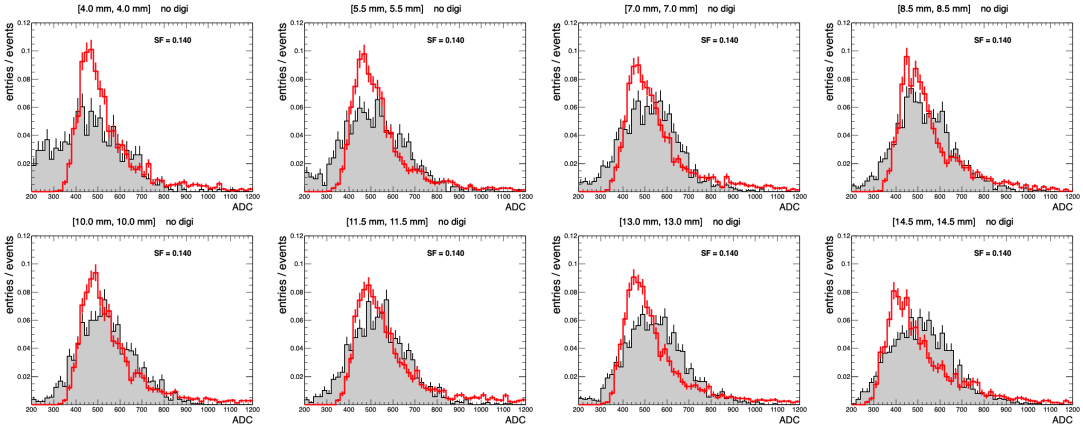
Tail to higher responses in MC larger than in data.

Exact behaviour near tile edges due to experimental trigger conditions is not simulated.

Tile boarders are excluded from data-MC comparison.

Comparison of data and simulations (no digitisation)

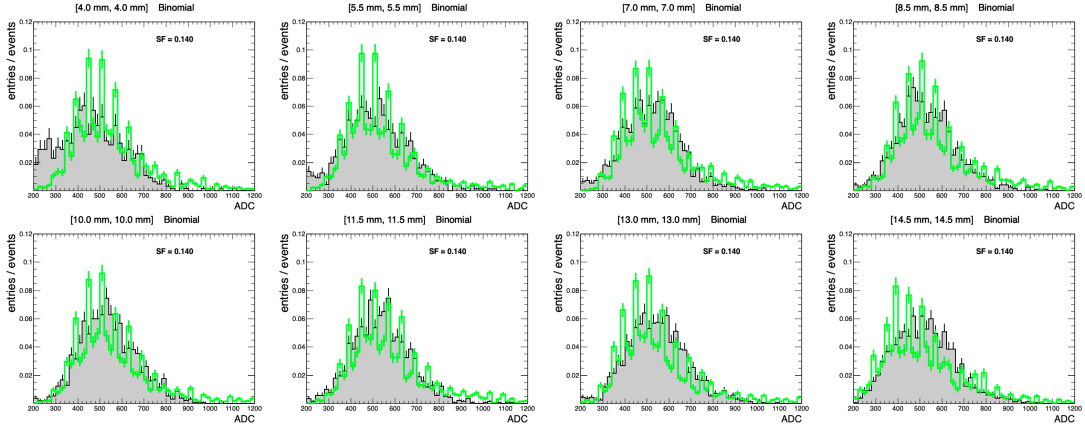
Data and **simulation**; at scan positions on tile diagonal



Landau-like behaviour of simulations as expected.
Additional smearing is necessary.

Digitisation tuning (+binomial smearing)

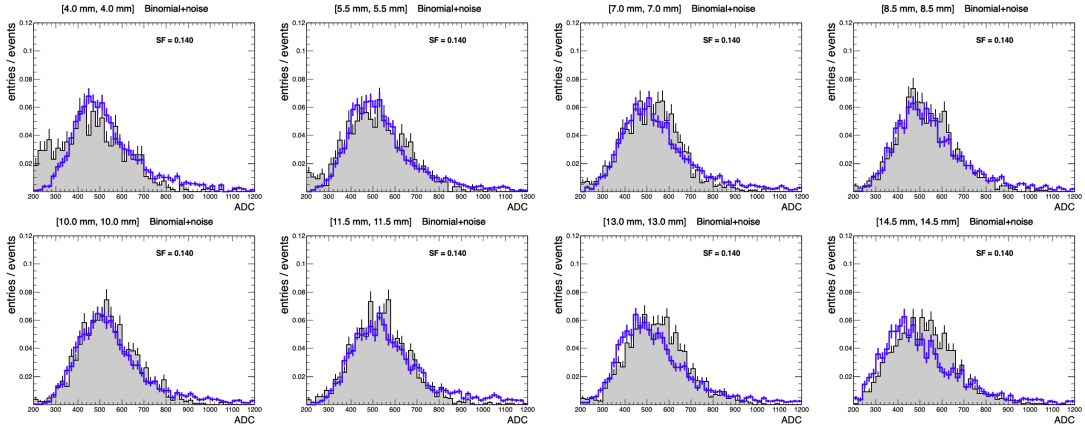
Data and **simulation**; at scan positions on tile diagonal



Binomial distribution describes the pixel-level photon detection in SiPM.

Digitisation tuning (+ binomial + noise)

Data and **simulation**; at scan positions on tile diagonal

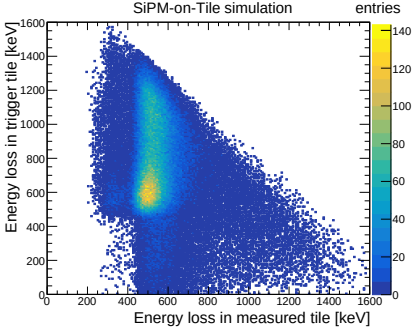


Results in good agreement between data and MC.

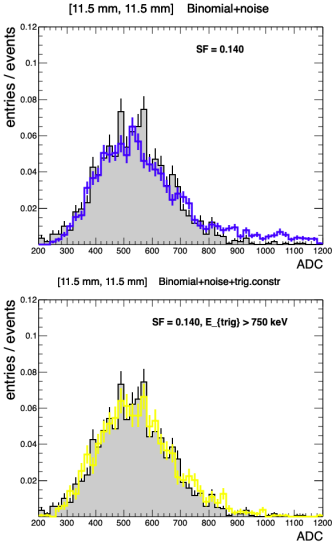
Near-edge distortion of experimental distribution is still visible at 4 mm from the tile edge.

Trigger treatment in data and simulation

Experiment: threshold trigger (tile with SiPM readout, optimised for appropriate S/N)
Simulation: deposition in trigger tile saved for offline treatment



Large energy deposition detected in the measured tile is related to the low deposition in trigger tile. *Better understanding is necessary.*

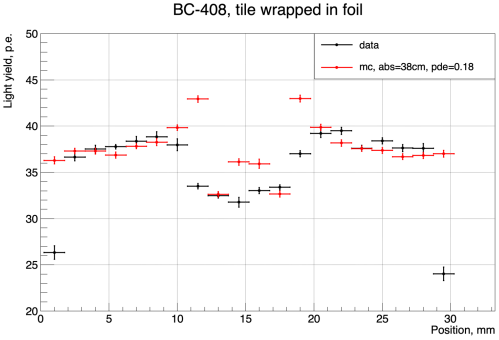


With additional constraint $E_{trig} > 750$ keV on simulated deposition in trigger tile, good agreement between data and MC is achieved.

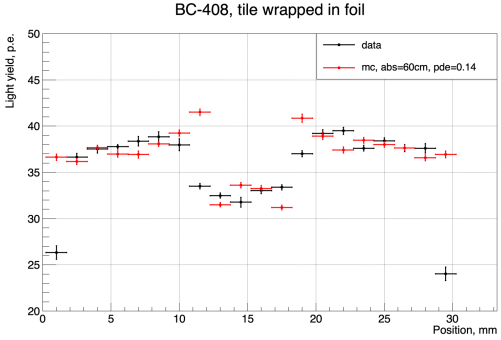
Tuning of attenuation length in simulation: 38 cm and 60 cm

- Comparison of light yield for **experimental data** and **Geant4 simulation**
- Linear scan through the center of the tile
- Scale factor (pde) is adjusted for each attenuation length value to be consistent with data in the ranges [2 mm,10 mm] and [20 mm,28 mm]

Simulated att. length = 38 cm



Simulated att. length = 60 cm

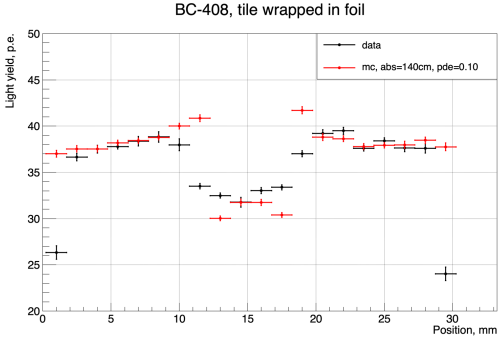


Better agreement between data and simulation for 60 cm is observed.

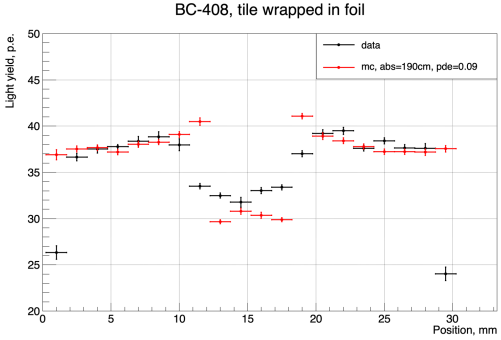
Tuning of attenuation length in simulation: 140 and 190 cm

- Comparison of light yield for **experimental data** and **Geant4 simulation**
- Linear scan through the center of the tile
- Scale factor (pde) is adjusted for each attenuation length value to be consistent with data in the ranges [2 mm,10 mm] and [20 mm,28 mm]

Simulated att. length = 140 cm



Simulated att. length = 190 cm



Behaviour in the dimple is not reproduced.

Summary

Simulation of scintillator elements of highly granular calorimeter

- **object**: scintillator tile $30 \times 30 \times 0.3$ mm^3 wrapped in foil and read out by SiPM
- **tool**: optical photon transport from Geant4 package with photon counting regime and without simulation of SiPM
- realistic readout parameters and **one scale factor as effective photodetection efficiency**

Validation of simulation

- digitisation schema with Binomial smearing and additive Gaussian noise is confirmed
- **good agreement between data and simulations in the shape of response is achieved except for tile edges**; slight shift is observed between data and simulated distributions near the center of the dimple
- variation of attenuation length shows better agreement with experimental data for 60 cm in BC-408 tile $30 \times 30 \times 0.3$ mm^3