First SiPM digitization studies for the IDEA DR calorimeter

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SiPM digitization (pySiPM)

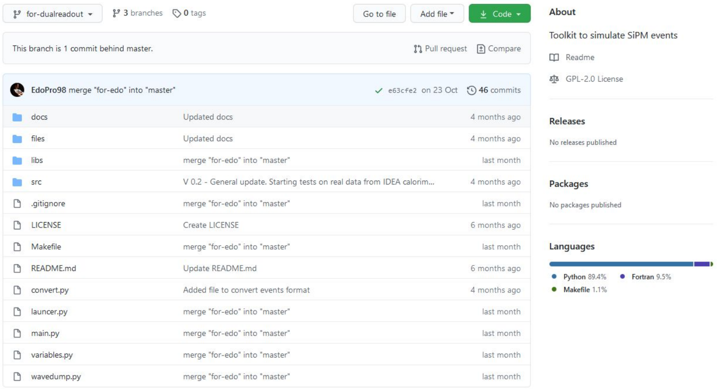
pySiPM can provide useful features such as:

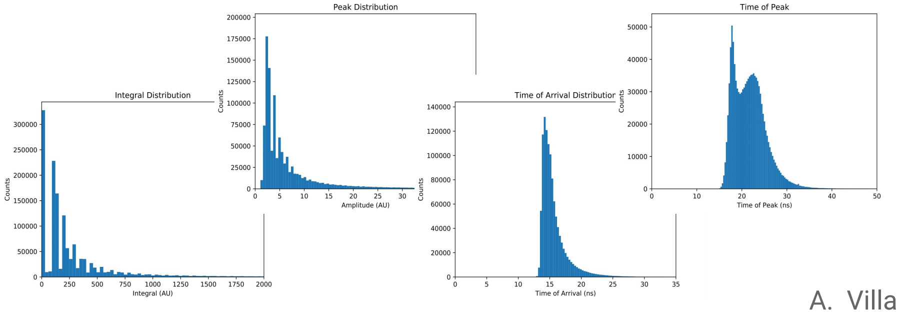
- Peak height
- Charge integral
- Time of Arrival
- Time over Threshold
- Time of Peak

and, if needed, can bring back additional information coming from the input file. In our case these information from DR-calorimeter simulation are:

- Fibre ID
- Fibre position (x, y, z)
- Type of fibre (Cherenkov, Scintillating)

It can also provide a digitized waveform as output from each SiPM.





DR-calorimeter simulation (Geant4)

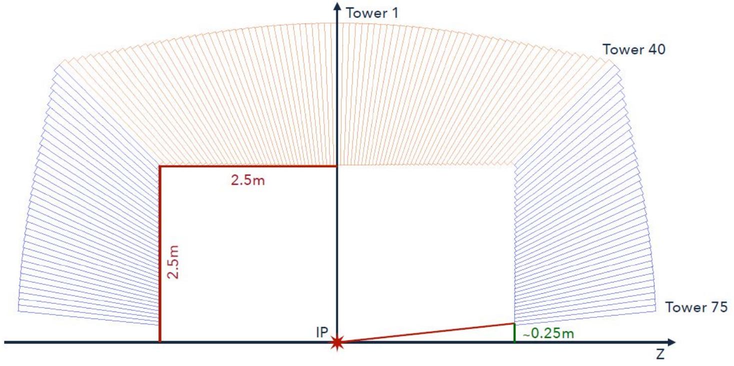
The calorimeter is composed by several towers, covering $\Delta\vartheta$=1.125° and $\Delta\varphi$=10.0° each.

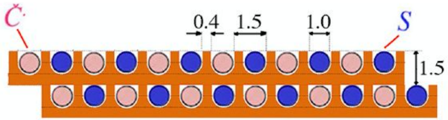
2 m long copper based towers.

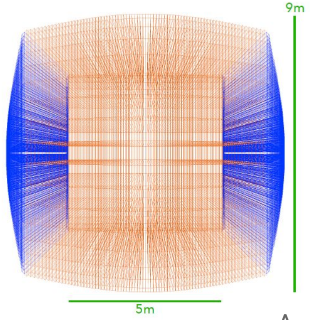
Towers in barrel: 40×2×36 = 2880
Towers per endcap: 35×36 = 1260

Towers are filled with two types of optical fibres for Cherenkov (C) and Scintillating (S) photons.
Each fibre is coupled to a dedicated SiPM.

Electrons and pions are produced at the IP with different energies (20 - 40 - 60 - 80 GeV).







SiPM parameters

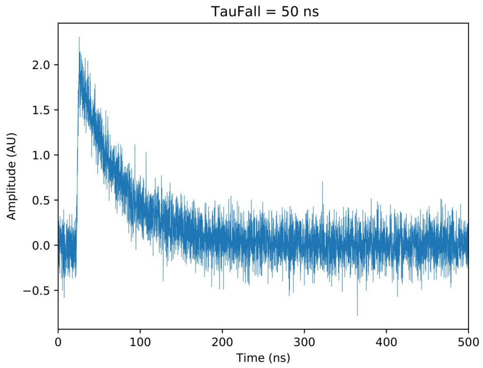
Most of the SiPM parameters can be easily modified.

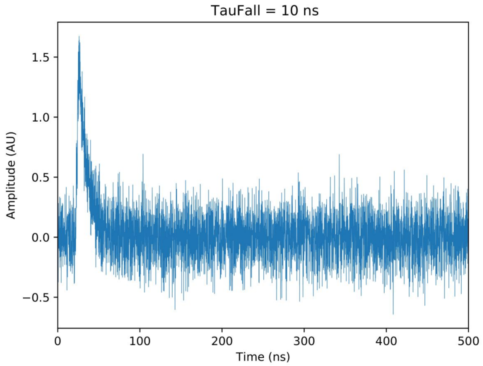
Signal Length: 500 ns
Sampling: 0.1 ns

SiPM Size: 1 x 1 mm^2
Cell Size: 25 x 25 μm^2
Dark Count Rate: 200 kHz
CrossTalk: 1 %
After Pulse: 3 %

Decay Time Constant: 50 or 10 ns
Rise Time Constant: 1 ns

Integration Start Time: 5 ns
Integration Time Window: 300 ns





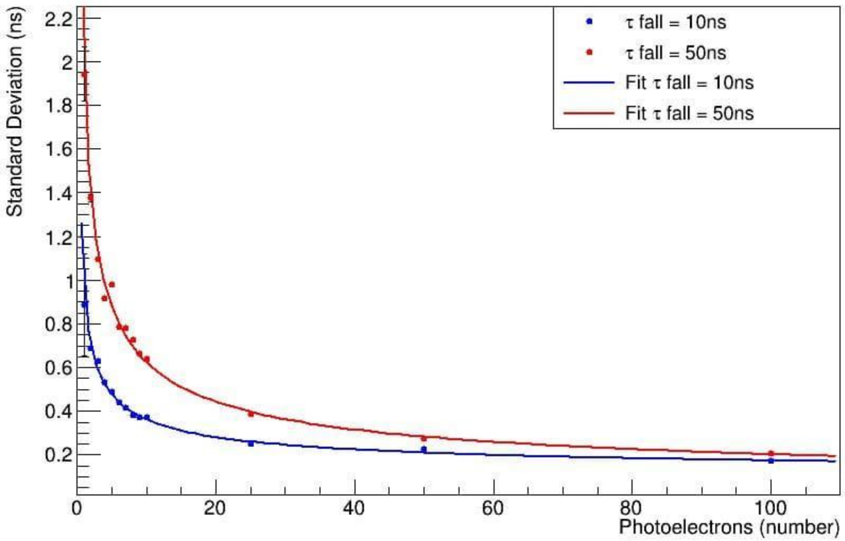
Peak time resolution (1/2)

We generate **13 samples** with an increasing number of photoelectrons (from 1 to 10, then 25, 50 and 100) with the same Time of Arrival at the SiPM interface. In each sample we have fired **10000 SiPMs**.

We record the **time of peak** from the digitization software and put them in 13 histograms (one for each sample).

By fitting them with a gaussian function we find standard deviation.

This process has been made with two different SiPM fall times (**10 ns** and **50 ns**). For each sample, we evaluated the standard deviation of the gaussian fit applied to the time of peak distributions.



Peak time resolution (2/2)

The behaviour of the standard deviation with respect to the number of simultaneous photoelectron (n) fired on the SiPM follows the law:

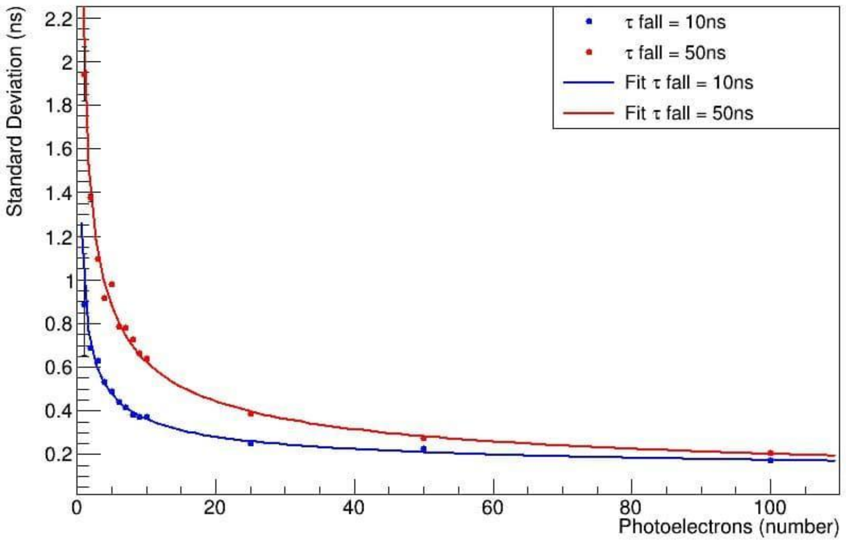
$$\sigma = \frac{A}{\sqrt{n}} + B$$

Fall Time Constant: 10 ns

A = 0.8712 ns
B = 0.0873 ns

Fall Time Constant: 50 ns

A = 1.9490 ns
B = 0.0082 ns



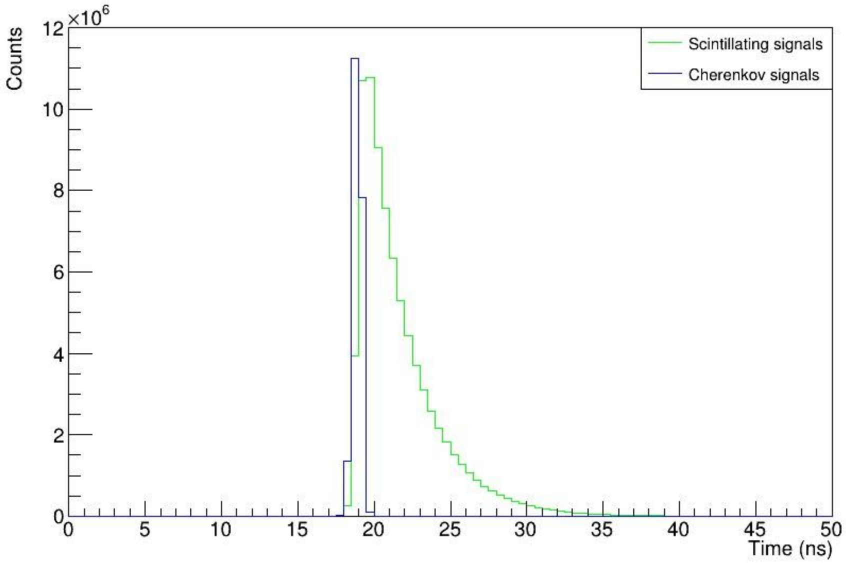
Time distribution of photons

We simulated 10000 events with single **20 GeV electron**.

First we focused on the Geant4 time of arrival of the photons at the end of the fibres.

The long tail for scintillating photons is due to the characteristic emission time of Polystyrene (τ = 2.8 ns).

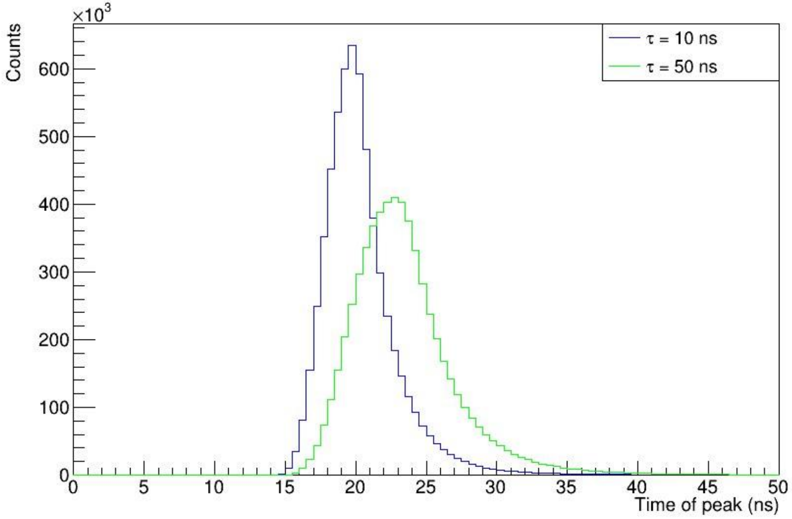
Time of arrival on SiPM surface



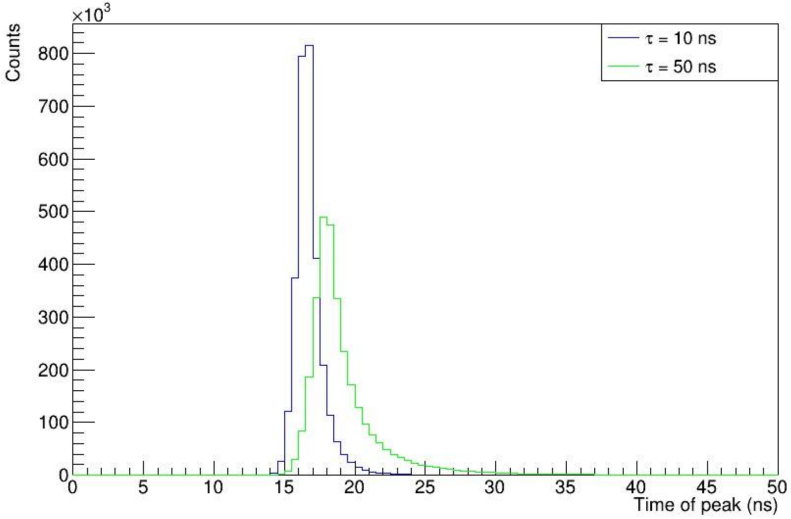
Time of peak

The events generated has been used as input of *pySiPM* using two different SiPM decay time constant.

Scintillating signals

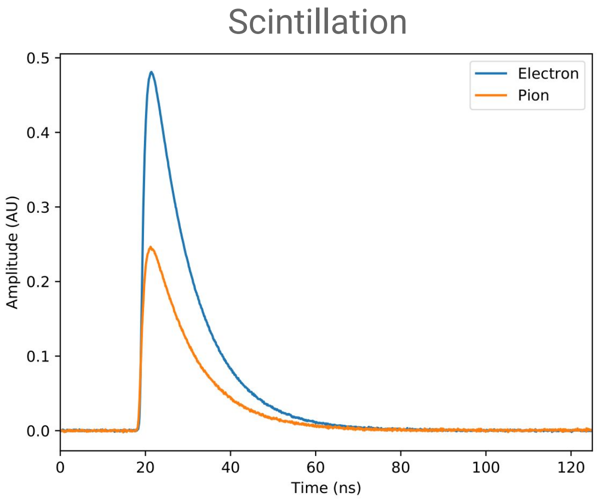


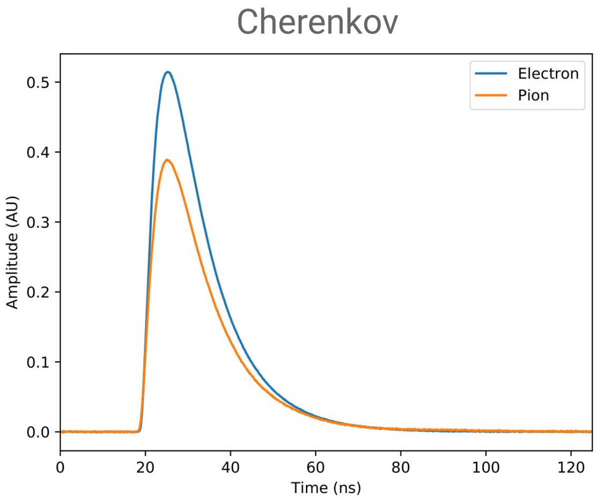
Cherenkov signals



Integrated waveform

Considering one event at a time, we analogically added the signals coming from the same type of fibres. Below there is an example comparing a typical signal from **40 GeV electron and pion**.





In this configuration, with a SiPM decay time constant of 10 ns, we found a small difference between the peak time of the two particle. The pion signals reach the peak of amplitude about 2~3 ns earlier.

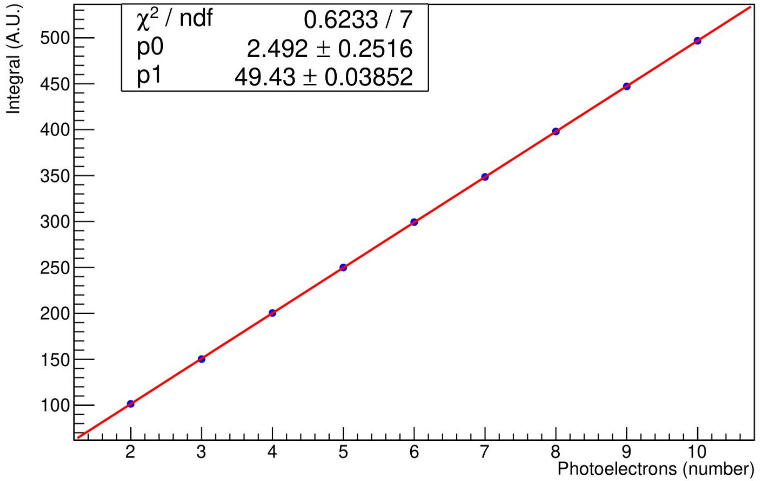
SiPM integral study

To provide a calibration function linking photoelectron number to the charge integral, we produced 10000 events with increasing number of pe from 2 to 10.

The plot sketched shows the mean values of charge integral with respect to the corresponding numbers of pe.

Fitting this data with a straight line we obtained:

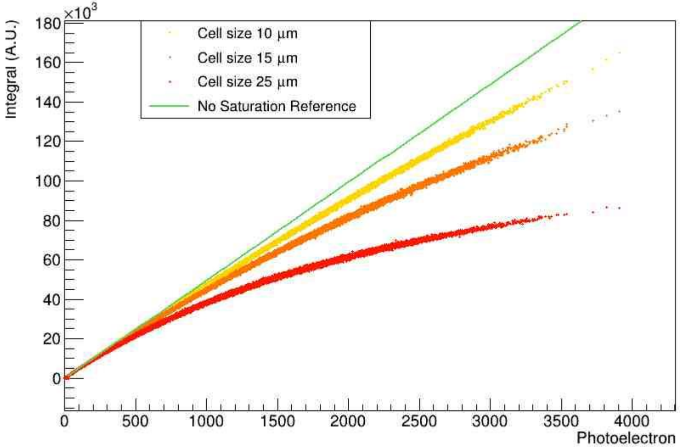
- p0: the pedestal due mostly to the DCR
- p1: the integral contribution of a single pe



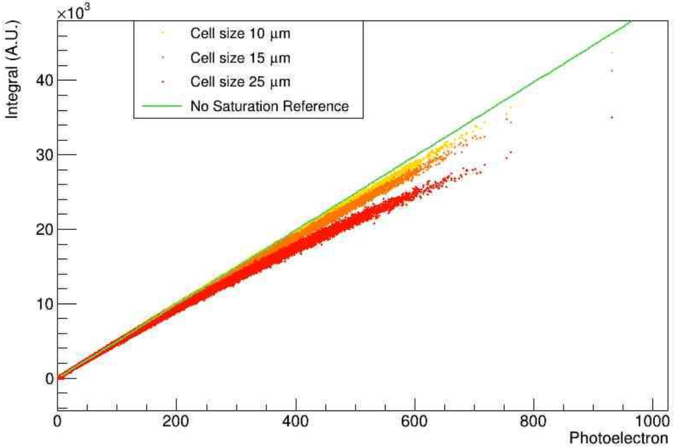
SiPM saturation (1/4)

By changing the parameter *Cellsize* we can increase the number of cells in each SiPM.
10000 events with a single **40 GeV electron** are considered, using a Light Yield of **~400 pe/GeV for scintillation** and **~100 pe/GeV for Cherenkov**.
We can plot the charge integral produced by each SiPM versus the number of pe (with the No Saturation Line as reference).

Scintillating signals



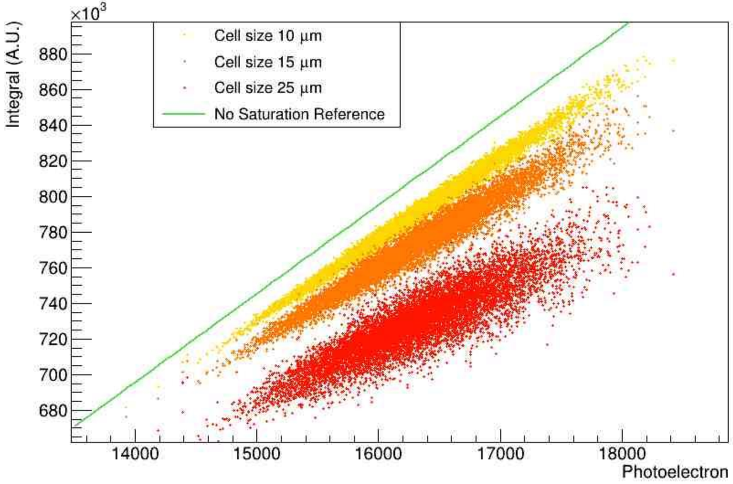
Cherenkov signals



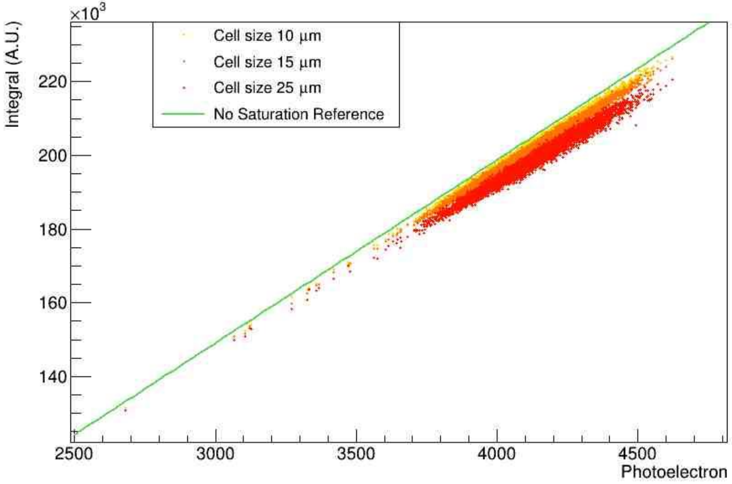
SiPM saturation (2/4)

Adding, event by event, the charge integral and the corresponding photoelectron numbers, we can study the impact of saturation in the energy reconstruction task.

Scintillating signals



Cherenkov signals



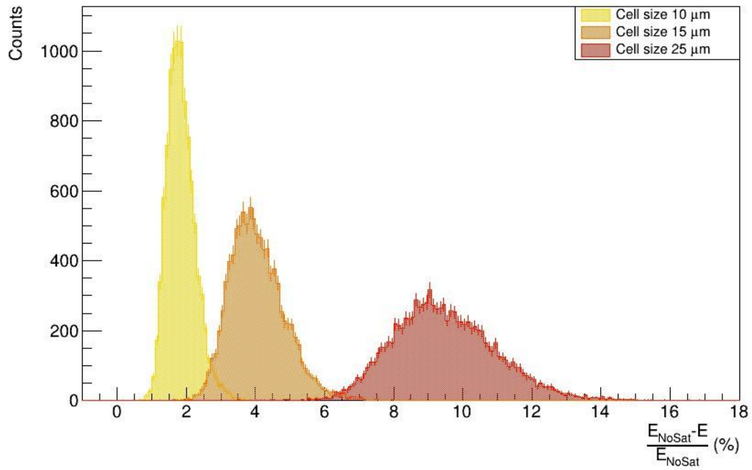
SiPM saturation (3/4)

Comparing each event integral to the *no-saturation* integral with the formula $\frac{E_{NoSat}-E}{E_{NoSat}}$

The mean percentage discrepancy obtained for **40 GeV electrons** are:

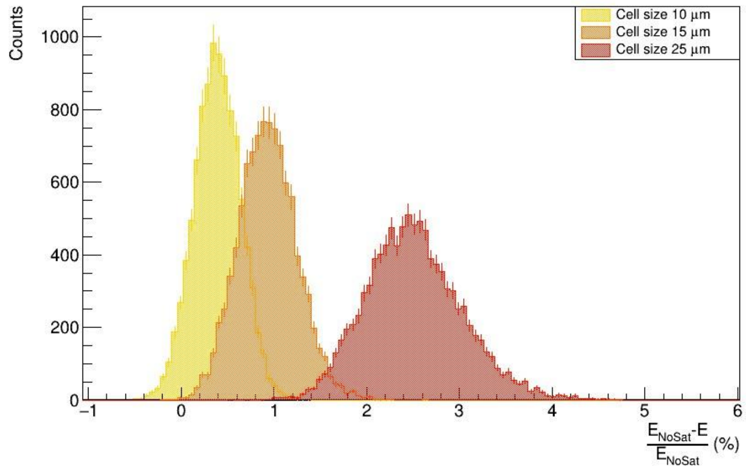
Scintillating signals

1.84% (10 μm) - 4.05% (15 μm) - 9.47% (25 μm)



Cherenkov signals

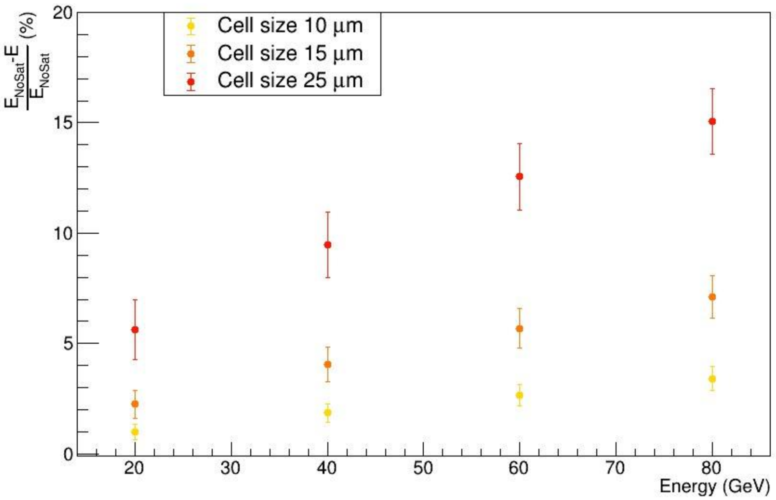
0.57% (10 μm) - 0.93% (15 μm) - 2.51% (25 μm)



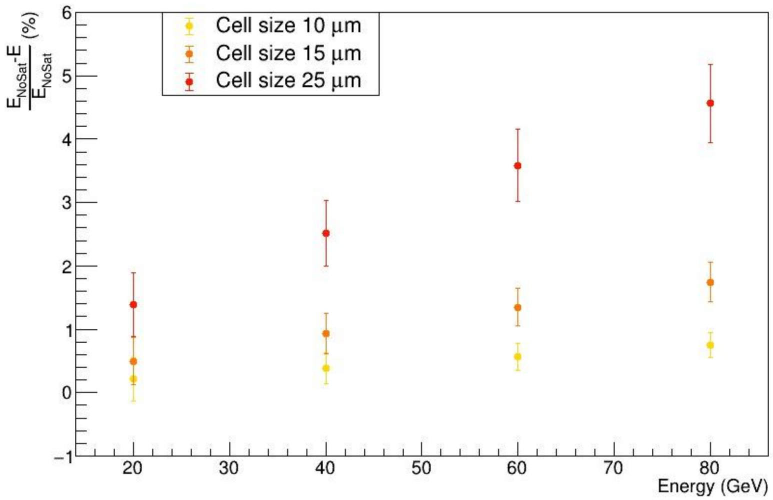
SiPM saturation (4/4)

We performed the same process with electrons of different energies (20 - 40 - 60 - 80 GeV) without applying any correction.

Scintillating signals



Cherenkov signals



The discrepancy of Cherenkov signals is less than 1% for 10 μm cell size SiPMs, meanwhile is ~3.5% for scintillating signals. Possible solutions to achieve better results are decreasing the scintillating light yield or eventually decreasing even more the cell size.

Conclusion

- We saw the capability of *pySiPM* to simulate SiPMs with different features and the production on corresponding digitized waveforms.
- We studied the capability of finding the peak over the electronic noise in two different decay time constant of SiPMs condition.
- We analyzed the impact of the digitization on time distributions in signals generated with our IDEA DR calorimeter simulation.
- We performed a saturation study obtaining the impact on energy reconstruction.
- Each studies can be upgraded but they already show the sinergy and the utility of the IDEA DR calorimeter simulation and the SiPM digitization software.