Inclusion of cross-talk in ALLEGRO full simulation

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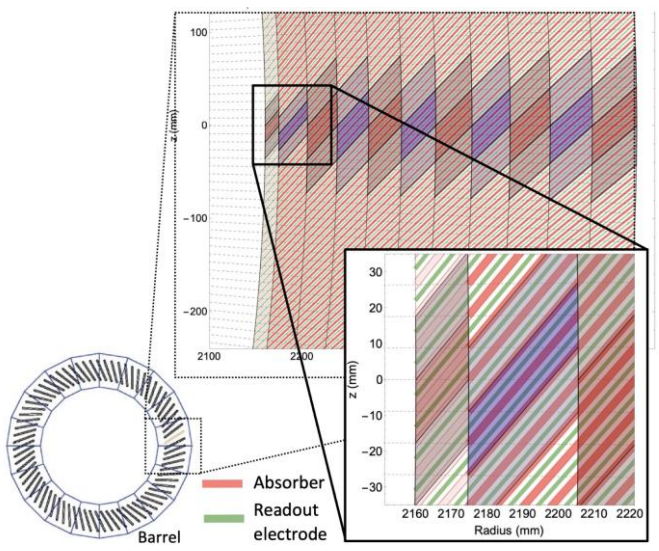
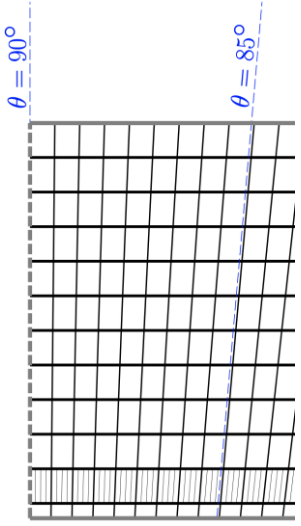
ALLEGRO detector concept

- A general purpose detector for FCC-ee (√s=90-360 GeV): A Lepton coLider Experiment with Granular calorimetry Read-Out. Detector concept.
- Key feature: High granularity noble liquid EM calorimeter (ECAL) and tile calorimeter.

Layout of ALLEGRO





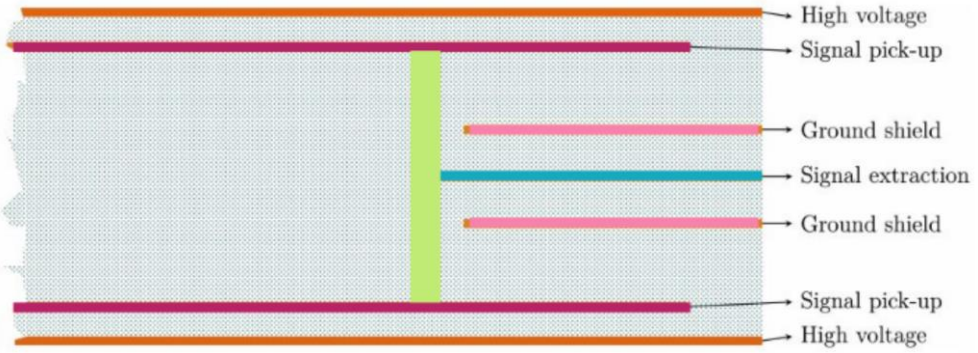
ALLEGRO ECAL

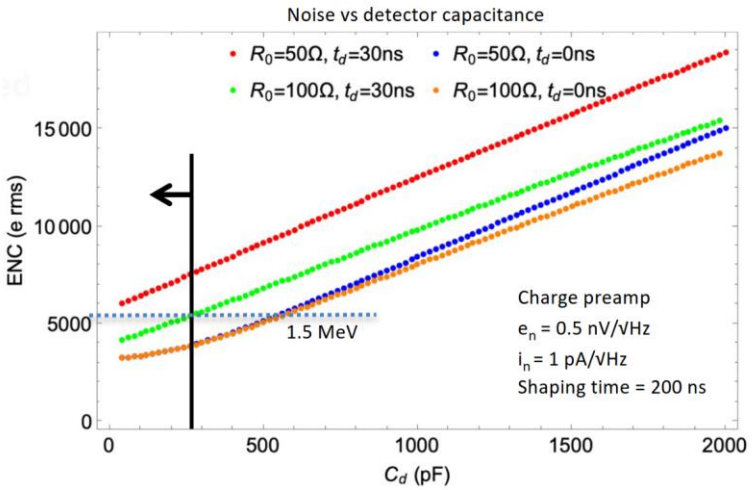
- Baseline: LAr+Pb
- Multi-layer PCB read-out electrode with inclination angle.

R&D's for the optimised physics performance, including photon-π^0 discrimination.

Read-out electrode structure

- Printed circuit board technology allows high granularity.
- Various couplings between calorimeter cells and signal traces inside the read-out electrode generate cross-talk → Needs for shielding.

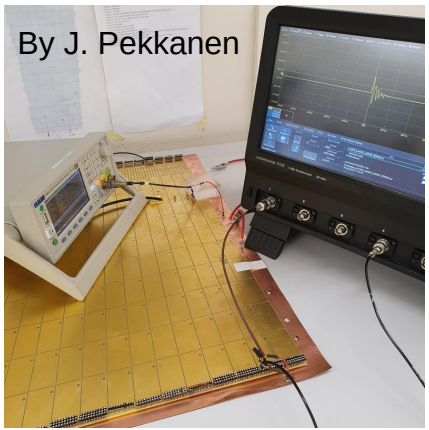




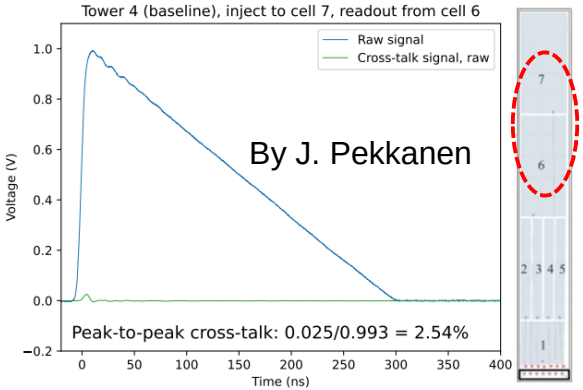
Side view of the 7-layer PCB for the read-out electrode.
Larger shielding suppresses cross-talk but increases electronic noise.

Measurement of electrode cross-talk

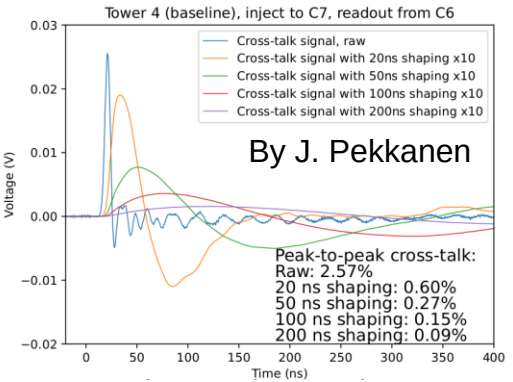
- Electrical properties of the electrode (CERN PCBv1) is measurement.
- Cross-talk impact on signal amplitude is reduced when the ionisation signal is processed by shaping filter. Longer shaping time results in smaller effect.



Lab setup at CERN:
(a) 300 ns wide 1 V peak is injected to the electrode at 5 ms intervals.
(b) Signals are read from the oscilloscope.

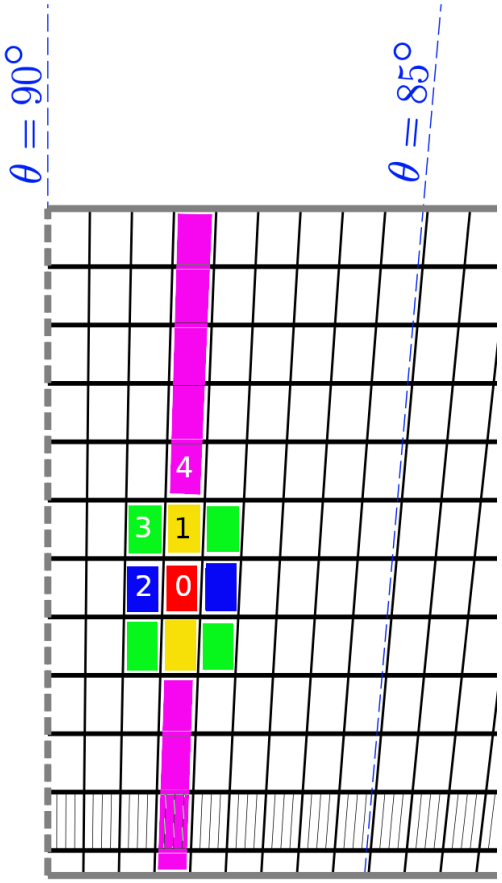


The shark-fin signal appears on the electrode receiving the injection, as well as the cross-talk on a radial neighbour.



Cross-talk can be efficiently reduced by introducing a pulse shaping (e.g. ATLAS-like RC-CR2 shaper) and choosing a long shaping time (e.g. 200 ns).

Cross-talk in the full simulation: Step 1



Schematic drawing of CERN PCBv1.

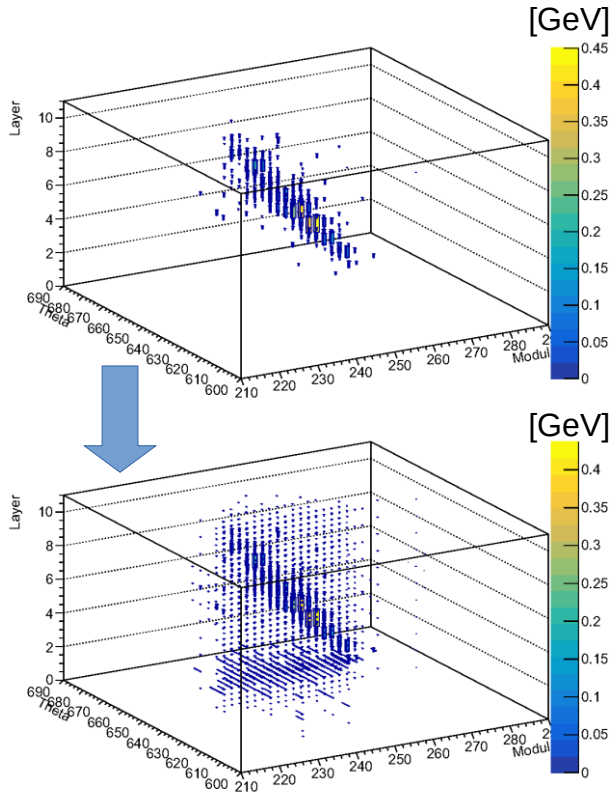
A map of cross-talk coefficient is generated for all ECAL barrel cells, including cross-talk neighbours and corresponding cross-talk coefficients.

- 4 types of cross-talk neighbours are accounted for in the emulation.
- Cross-talk coefficients are taken from the measurement on CERN PCBv1 with 50 ns shaping.

Type	1: Radial	2: Theta	3: Diagonal	4: Tower
Crosstalk	0.7%	0.3%	0.04%	0.1%

- Utility tools in k4geo loop over all ECAL cells and save the cross-talk map in ROOT format, as an input to the full simulation.

Cross-talk in the full simulation: Step 2



ALLEGRO ECAL signals in each cell for a 5 GeV photon shower, before and after adding cross-talk.

The cross-talk map is loaded in the full simulation, so that the cross-talk effect can be added to each event during reconstruction.

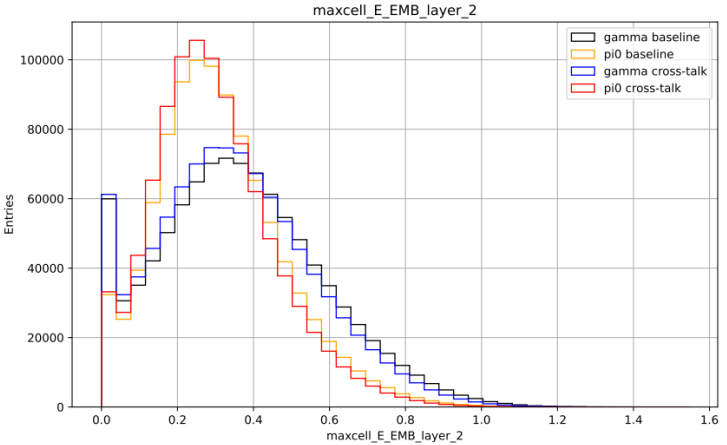
- In k4RecCalorimeter, the energy deposit of each ECAL cell is subtracted by the effect of cross-talk.
- The subtracted amount of energy is redistributed to cross-talk neighbours.
- The final energy in each cell after the calculation of cross-talk is taken to be the signal and passed to clustering algorithms.

Cross-talk and photon-π^0 discrimination

Very preliminary studied achieved with BDT*

- Produce 5 GeV photon and π^0 samples and run the event reconstruction.
- Save shower shape variables of the leading sliding-window cluster for each event, with and without cross-talk effect.
- Use shower shape variables to train two photon-π^0 separation BDT's, with and without cross-talk, respectively.
- Compare the ROC curves to understand the effect of cross-talk.

*A customised BDT is used for test purpose. The study can be repeated with the official PhotonID tool.

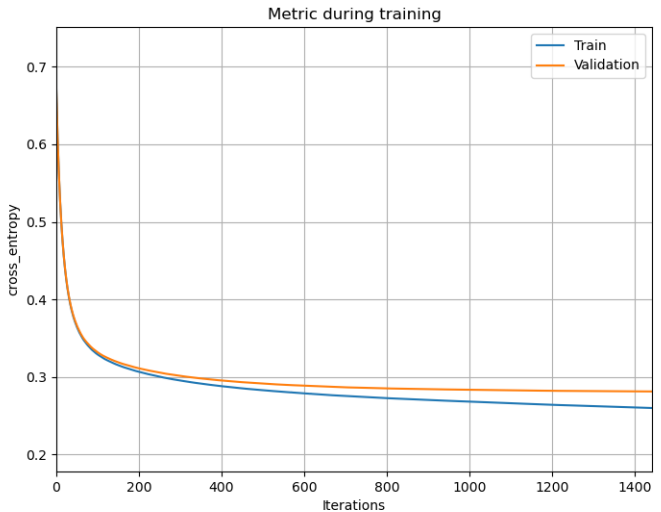


An example of shower shape variables: *The maximum cell energy on ECAL layer 2*.

990K photons and 980K π^0 with 5 GeV energy are produced.

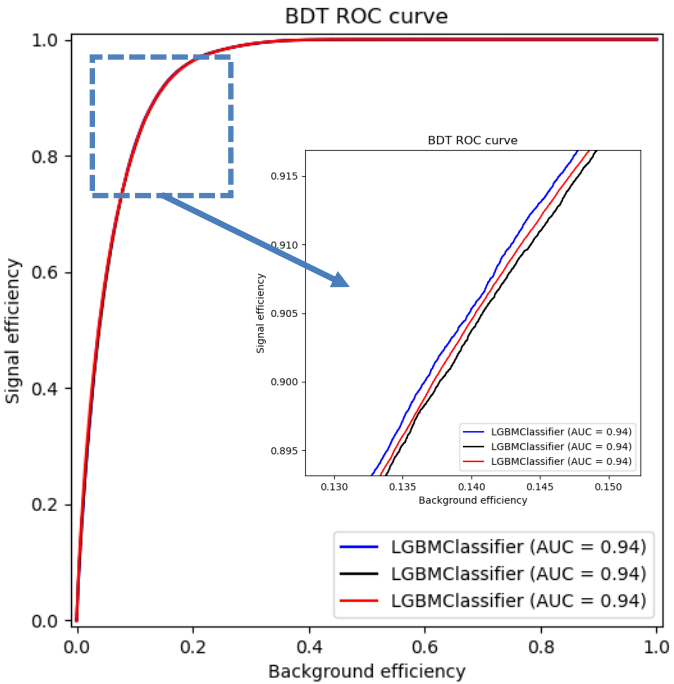
Cross-talk and photon-π^0 discrimination

Result of train-validation-test trainings with LGBMClassifier



Loss function (cross-entropy) vs iterations for the training on samples without cross-talk.

- **Blue**: No cross-talk in training or test.
- **Black**: Cross-talk in both training and test.
- **Red**: No cross-talk in training but cross-talk in test.



No significant dependence of photon-π^0 discrimination on the cross-talk in this study.

Summary

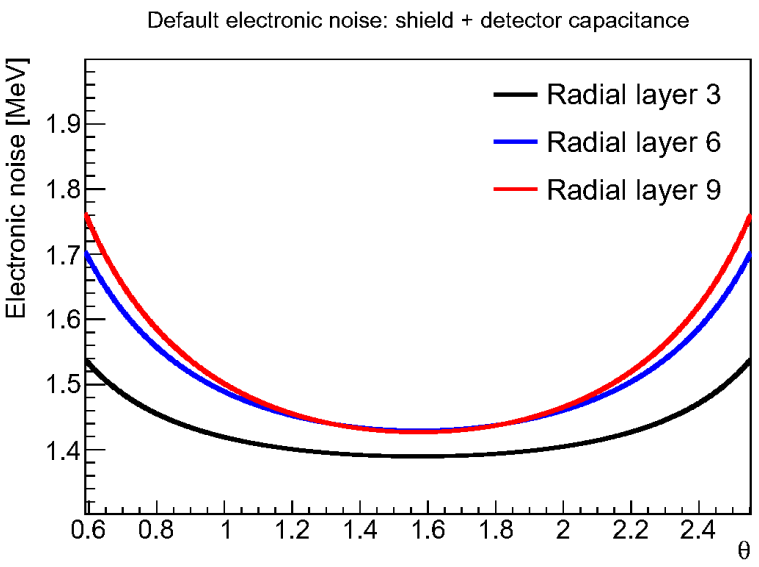
- The emulation of ECAL cross-talk has been implemented in the ALLEGRO full simulation to study the impact of cross-talk on physics performance.

- A preliminary study of photon-π^0 discrimination is carried out with BDT. No significant dependence of photon-π^0 discriminating power on cross-talk is observed so far.

- The cross-talk emulation will be updated to match new read-out designs. The photon-π^0 discrimination will be explored in a more realistic physics scenario (e.g. collisions at $\sqrt{s}$ =240 GeV).

Backup

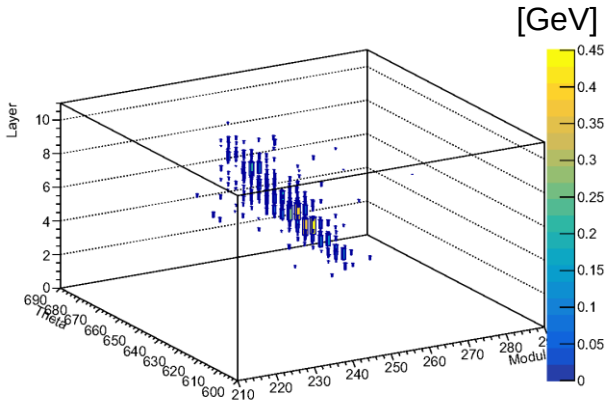
Implementation of electronic noise



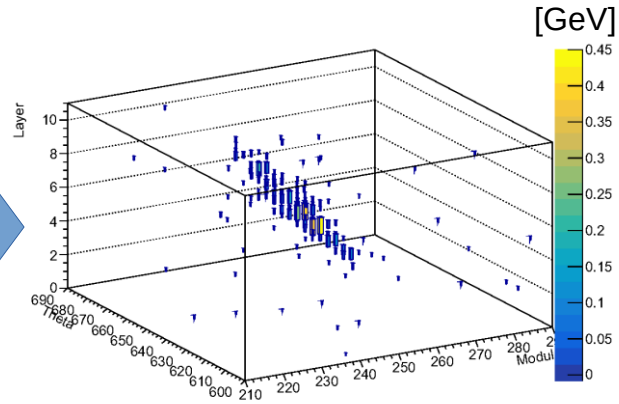
Estimation of electronic noise depending on radial layer and polar angle (unit in radian).

- The electronic noise on each ECAL cell is assumed to follow a Gaussian distribution centered at 0.
- The standard deviation of the Gaussian distribution is taken from a calculation mainly based on the size of the cell.
- During the reconstruction in the full simulation, the noise is sampled from each cell and added to its signal value.
- Noise filter: Cells with energy below a multiplier of the expected noise are removed from the output cell collection, before the cell collection is passed to clustering algorithms.

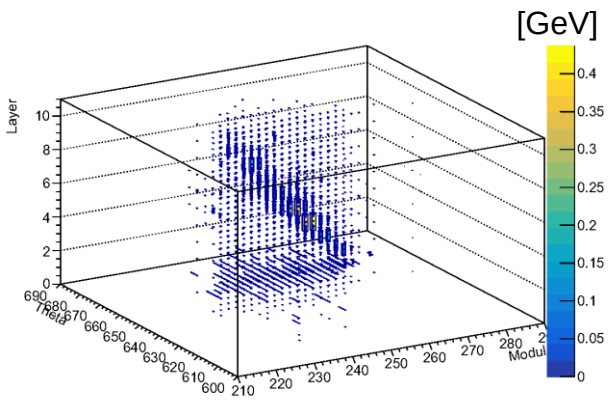
Distribution of cell signal



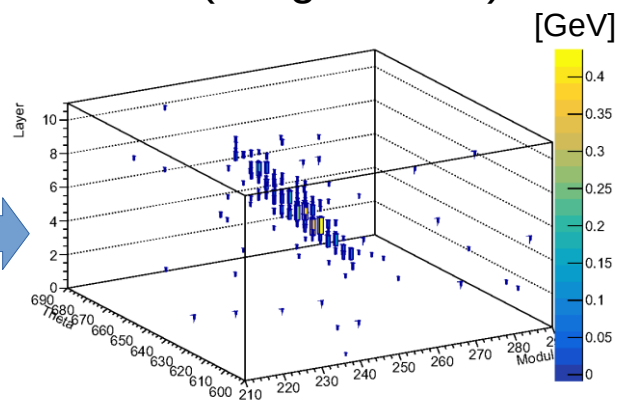
Baseline



Noise (3 sigma filter)



Cross-talk



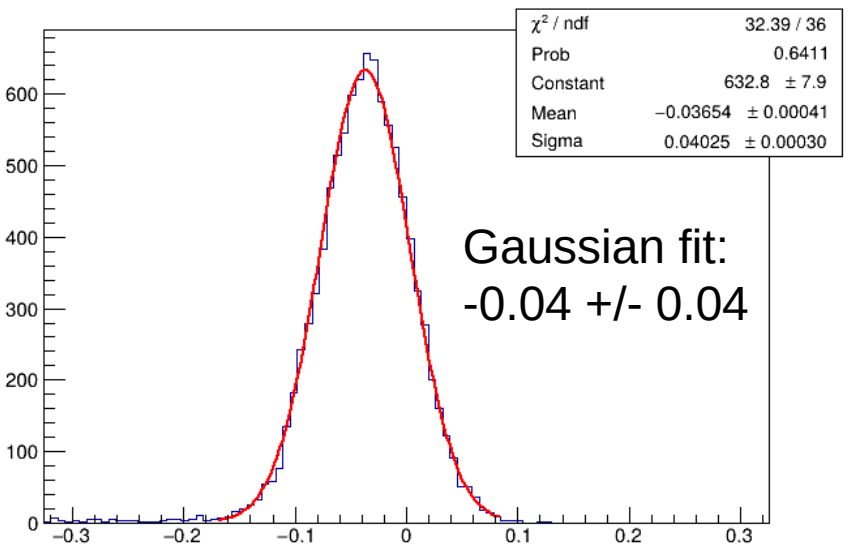
Cross-talk + noise
(3 sigma filter)

A 5 GeV photon is injected into ALLEGRO, but with different setups of cross-talk and noise.

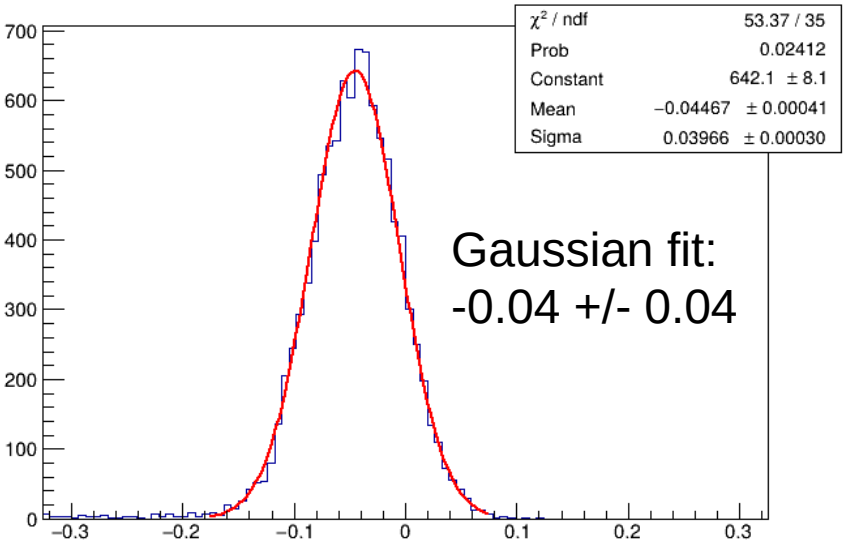
- The cross-talk smears out the energy deposit of the photon in the ECAL.
- With the addition of electronic noise and noise filter, no visible distortion is observed for the core part of the shower.

Energy response

Noise (1 sigma filter)



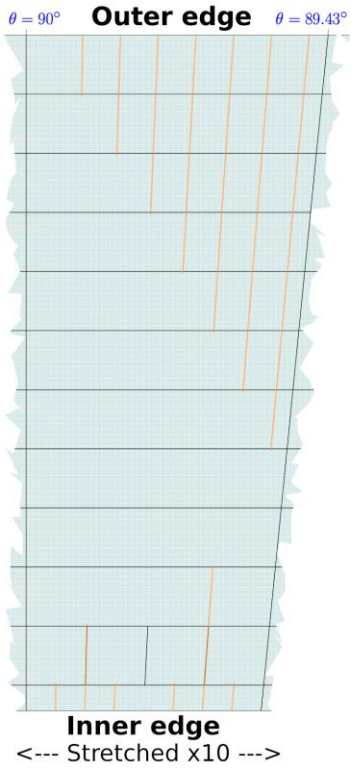
Cross-talk + noise (1 sigma filter)

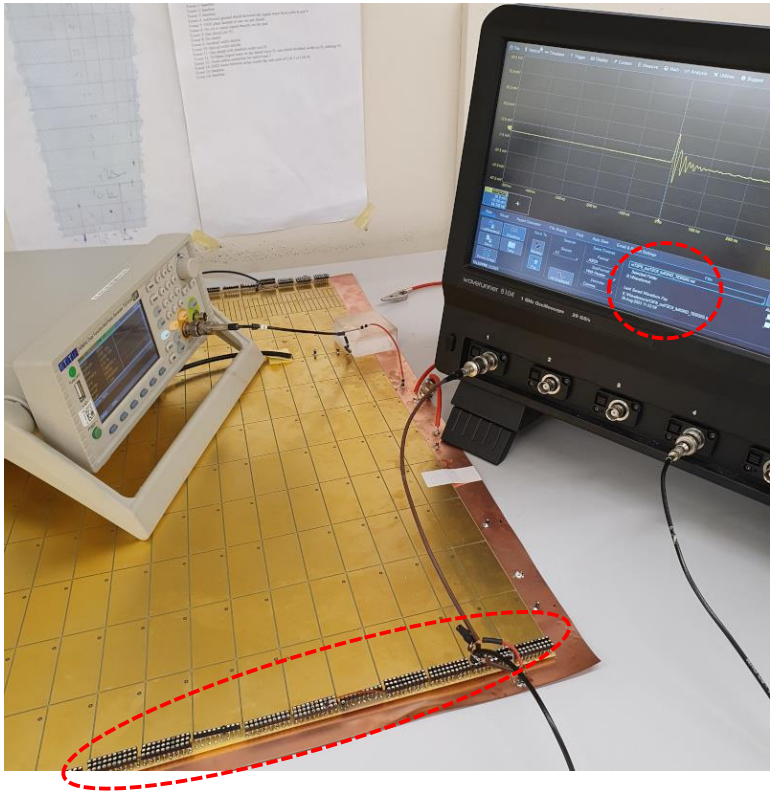


- Energy response = (E_reco – E_true) / E_true
- Distributions of energy response are studied with 10K 5 GeV photons, using CaloTopoCluster.
- The presence of cross-talk does not degrade the photon energy resolution.

The read-out scheme

- Signals are extracted from both the inner and outer radial edges, depending on the layer.

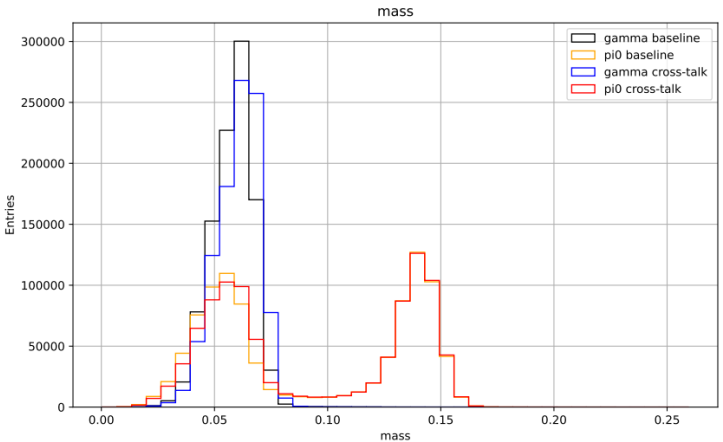




In IJCLab prototype and next CERN prototype, read-out is designed only from the outer edge in order to minimise the amount of dead material in the front.

List of shower shape variables

- The shower invariant mass.
- E_fr_side_pm3_EMB_layer*
- energy_fraction_EMB_layer*
- maxcell_E_EMB_layer*
- Delta_E_2ndmax_min(_vs_phi)_EMB_layer*
- width_module(theta)_EMB_layer*
- Ratio_E_max_2ndmax(_vs_phi)_EMB_layer*



Invariant mass of shower [GeV]