Simulation Study on Optical Crosstalk for AHCAL

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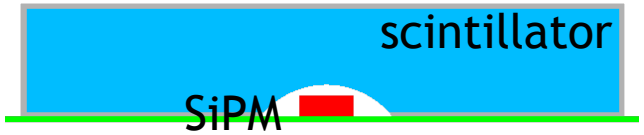
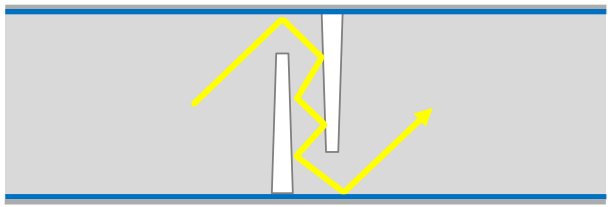
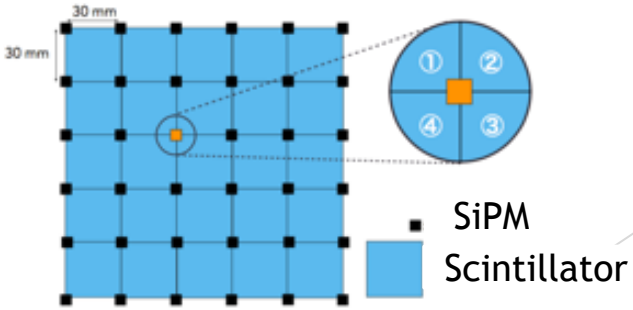
Possible Increase of Optical Crosstalk



- Baseline design of AHCAL :
  - The active layers are aligned 30mm x 30mm scintillator tiles with SiPMs at the center of the tiles
  - Each tile is wrapped with reflector foil individually
  - The optical crosstalk between tiles is estimated to be a few percent or lower
- Some other detector designs for mass production and performance improvement



megatile



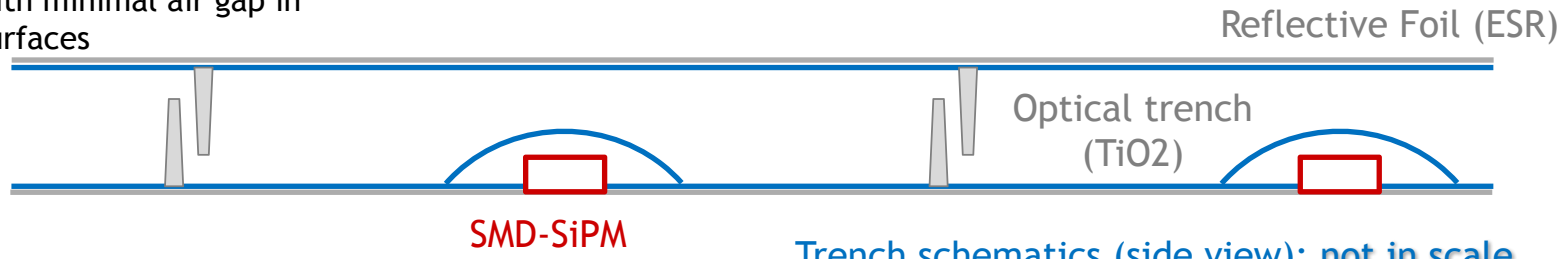
4 corner readout

-> Possible increase of optical crosstalk

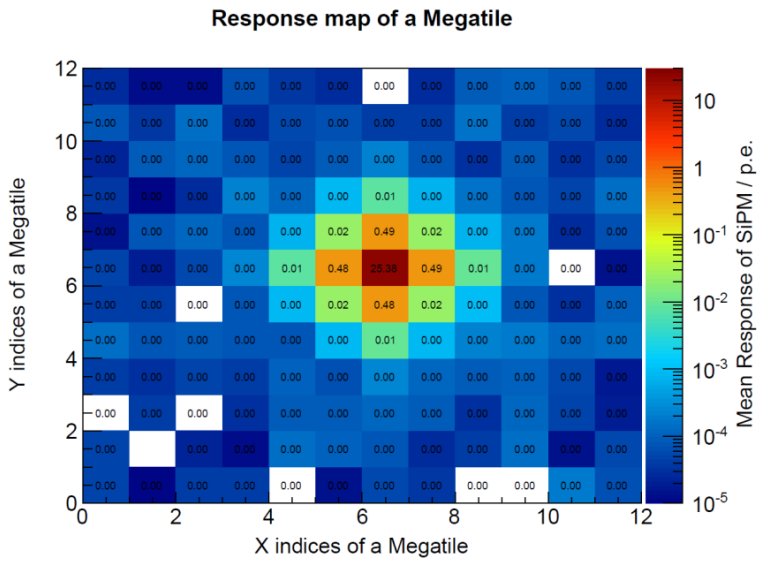
Megatile Recent Study

- According to a simulation with double trenches model, 1.8% crosstalk achieved

Trench parameters are 0.3mm wide, 0.3mm offset with minimal air gap in top & bottom surfaces



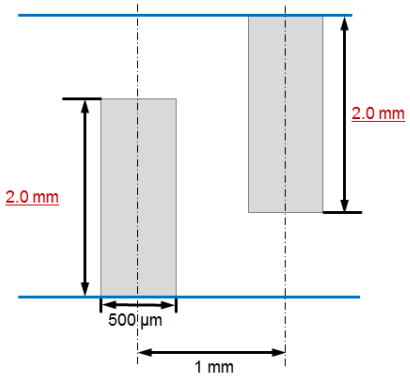
Trench schematics (side view): not in scale

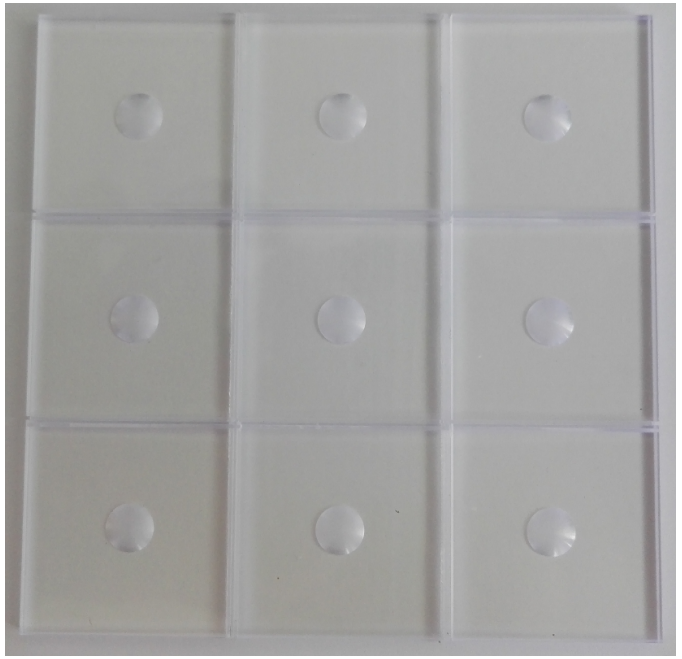


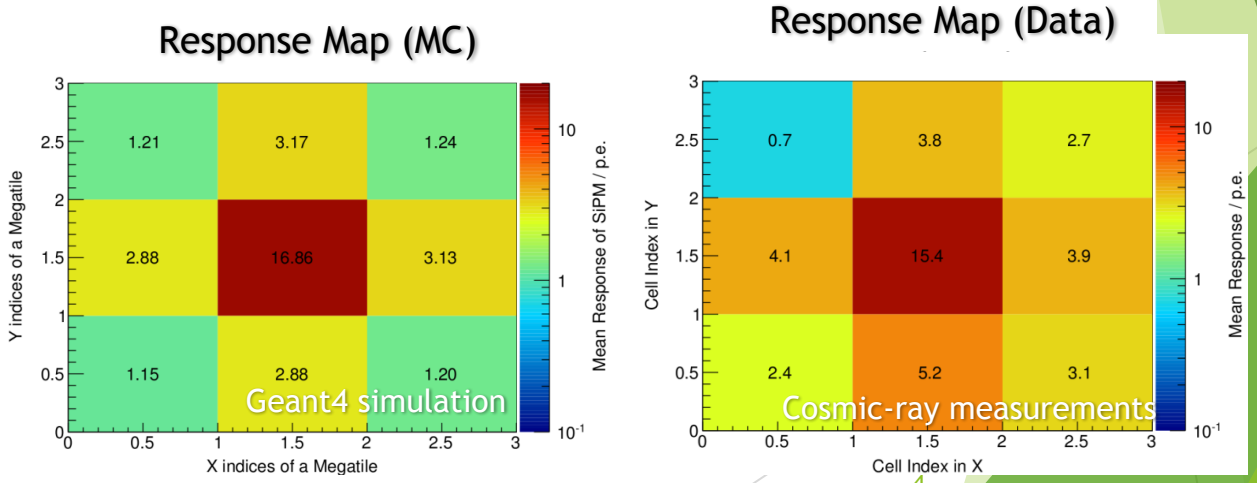
Central cell: 25.4 p.e./MIP
Neighboring cell: 0.49 p.e./MIP
Cell-to-cell crosstalk: 1.8 %

Megatile Prototype

- First prototype with less challenging parameters
  - 3x3 cells, 0.5 mm width 1 mm offset
- Similar MIP response and crosstalk in data and MC

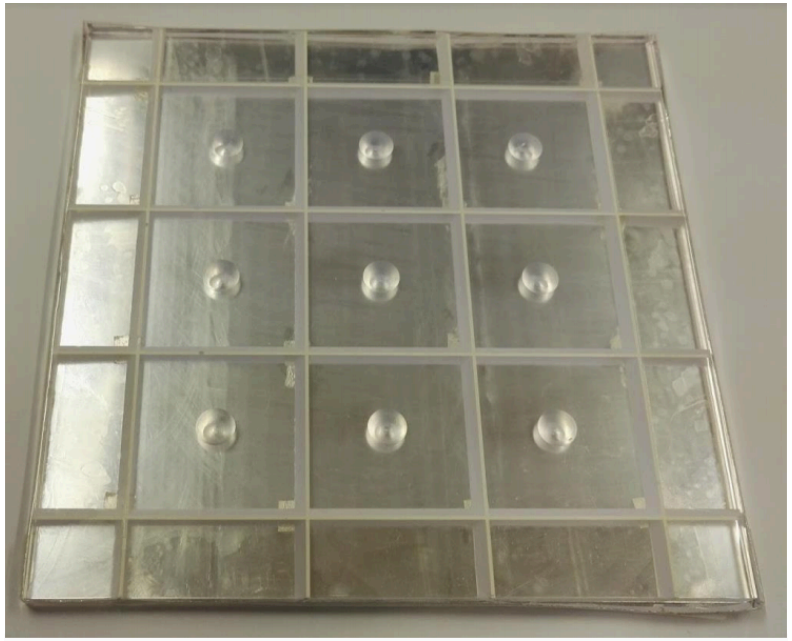




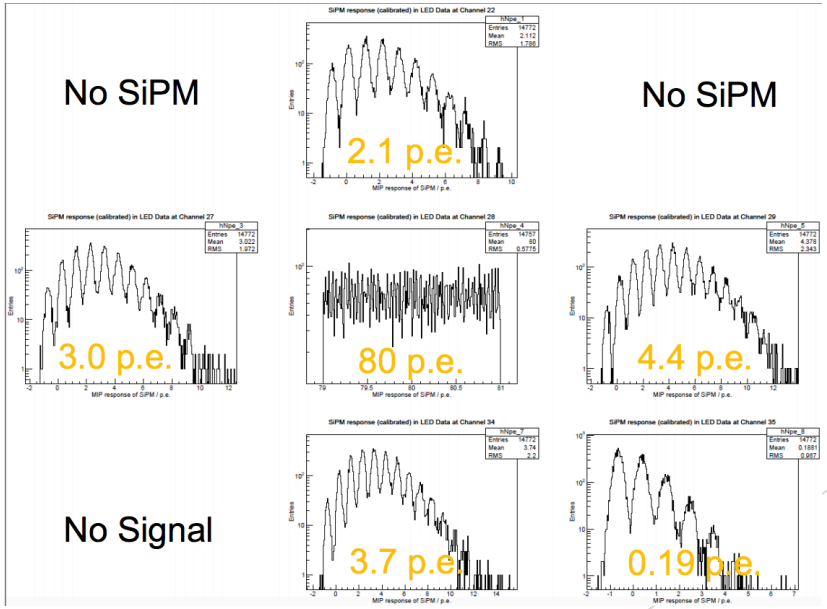


Megatile Prototype

- Setup with single trench design
- Optical crosstalk from airgap between the scintillator and the reflector



Mean crosstalk measured with LED signal: 4-5 %

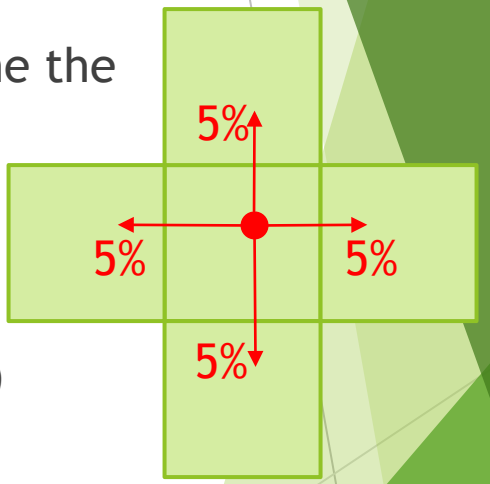


Objectives

- Simulate the effect of crosstalk on the calorimeter performance
  - Jet energy resolution
  - Particle separation
- Define the upper limit of crosstalk to retain the target resolution

Generating Crosstalk in Simulation

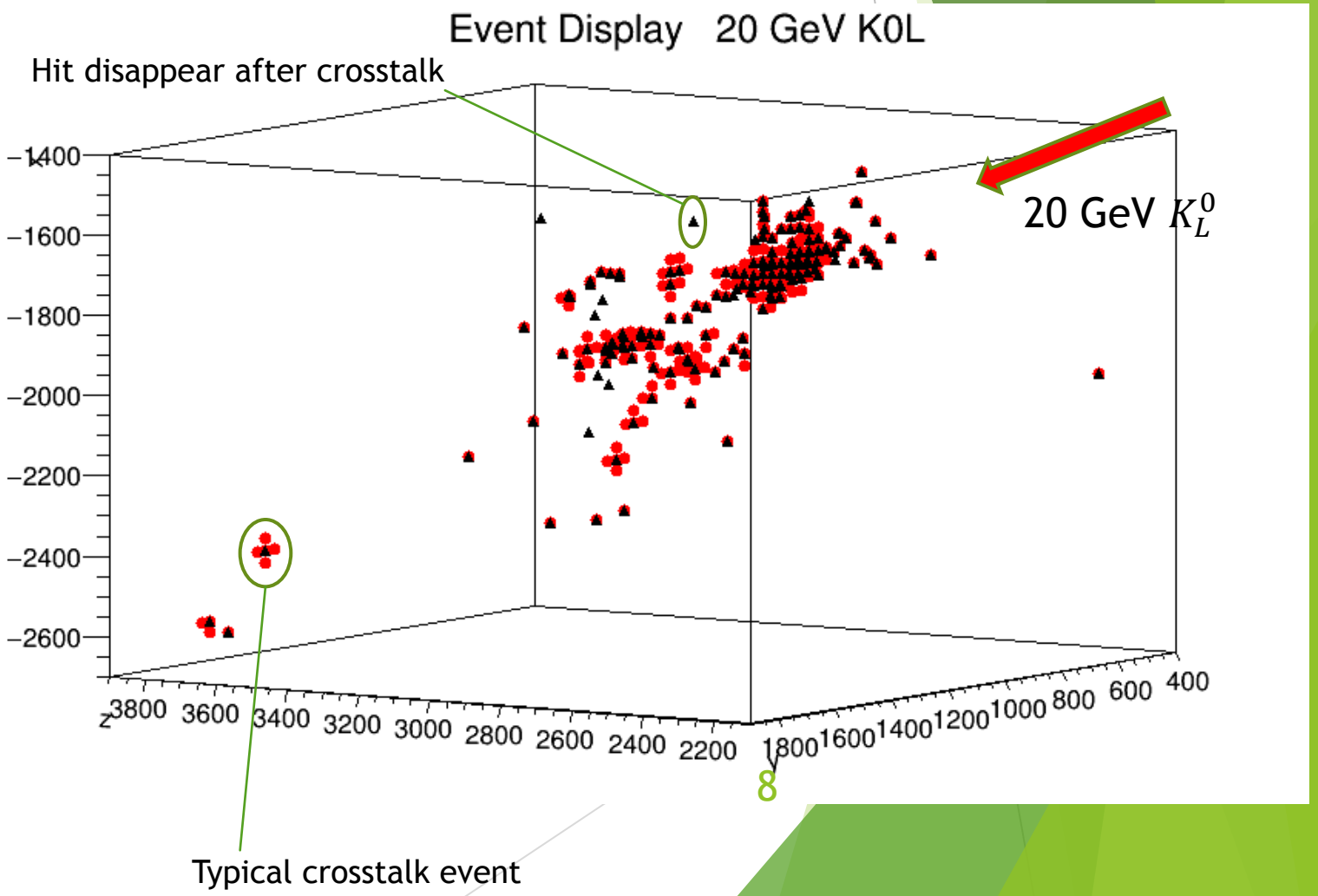
- For each energy deposit on scintillator tile, give some fraction of energy to neighboring tiles
- If there is already existing energy deposit on the neighboring tile, combine the original energy and the crosstalk energy
- Each energy deposit is digitized with threshold of 0.5 MIP



- Simulate di-jet events from quark pairs in DD4hep ILD model (ILD_l1_v01)
- ILCSoft version : v01-19-02
- Apply 1-20 % crosstalk and reconstruct with Particle Flow Algorithm

Event with crosstalk

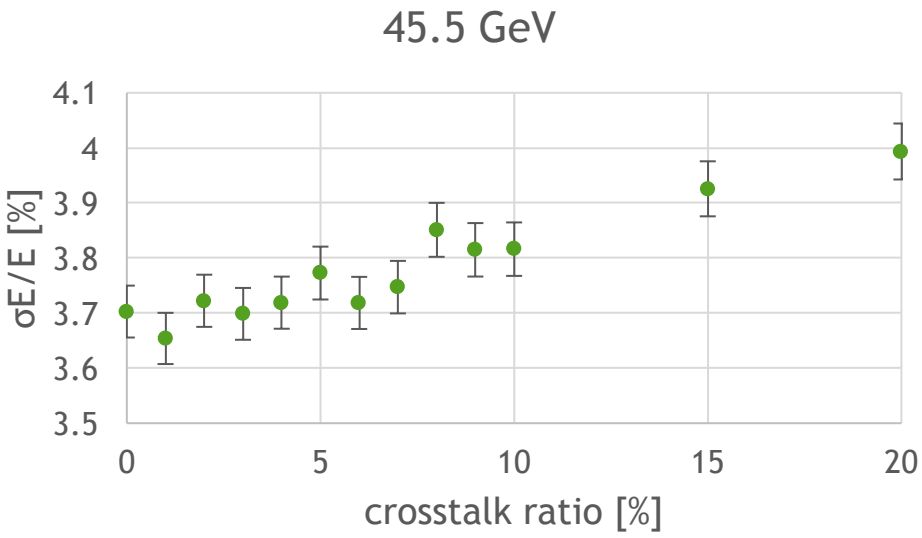
- Single neutral kaon injection
- Black : before applying crosstalk
- Red : after applying 10% crosstalk
- The shower get vague, and some hits energies fall below threshold

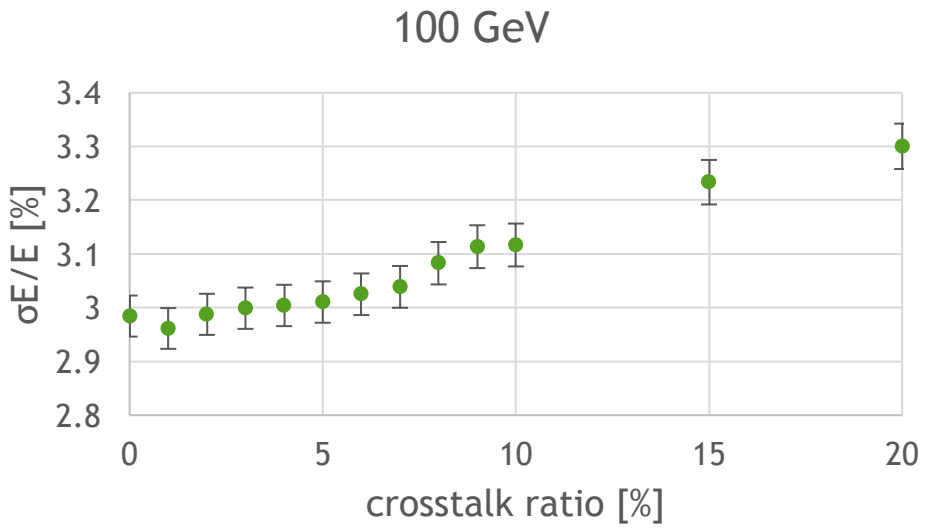


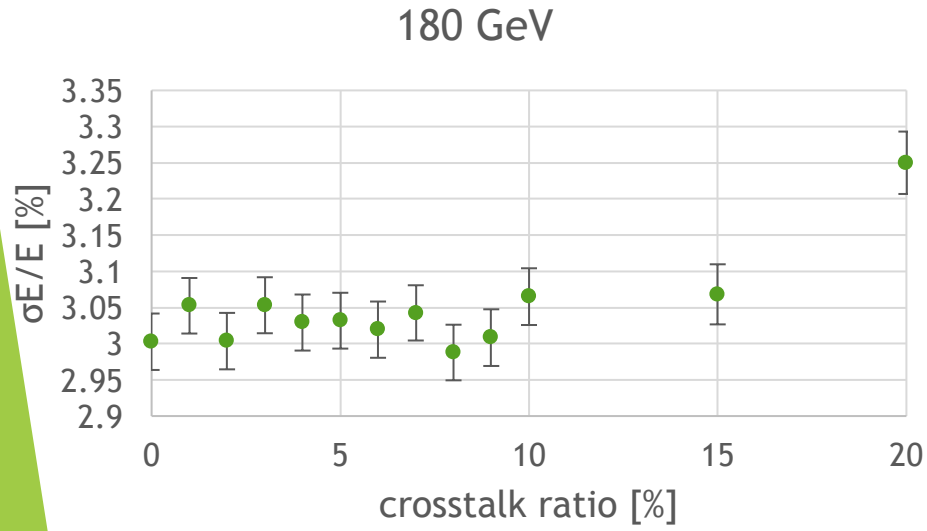
Analysis Calibration

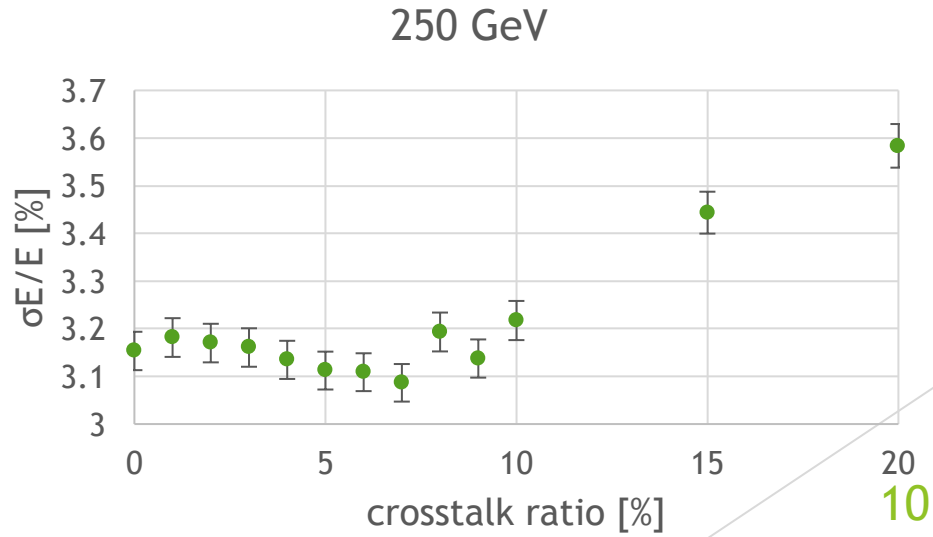
- Pandora Particle Flow Algorithm has to be finely calibrated
- Calibration Constants
  - MIP responses in digitization
  - MIP to GeV reconstruction constants
  - Correction of Ecal/Hcal response to EM/Had shower
- Optimize using muon/photon/kaon beams with already known energy

Jet Energy Resolution with Crosstalk





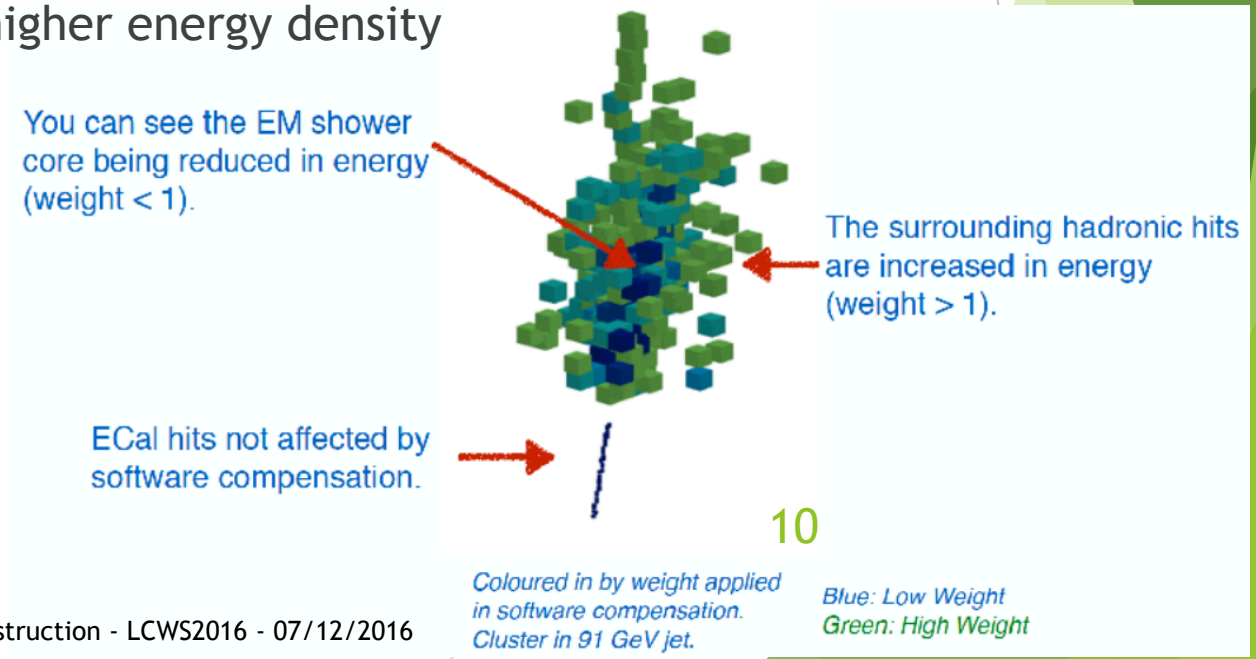




JER is clearly worse when the crosstalk is extremely high

Software Compensation

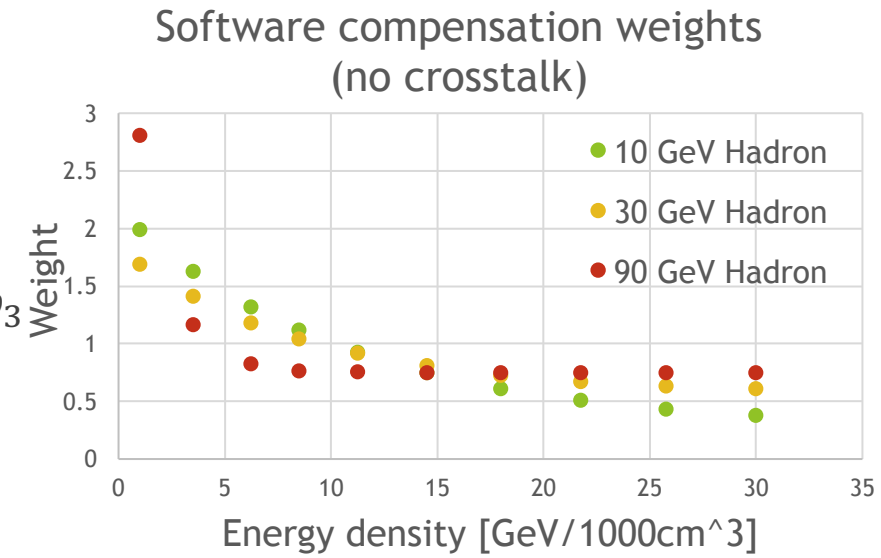
- There are some EM components in hadronic shower and the fraction of EM components differs from event to event
- The detection efficiency differs between EM and hadronic components
- Efficiency compensation is necessary for accurate reconstruction
- EM component is distinguishable for its higher energy density
- Apply more weight on the hadronic component than on the EM component
- ~20% resolution improvement by SC

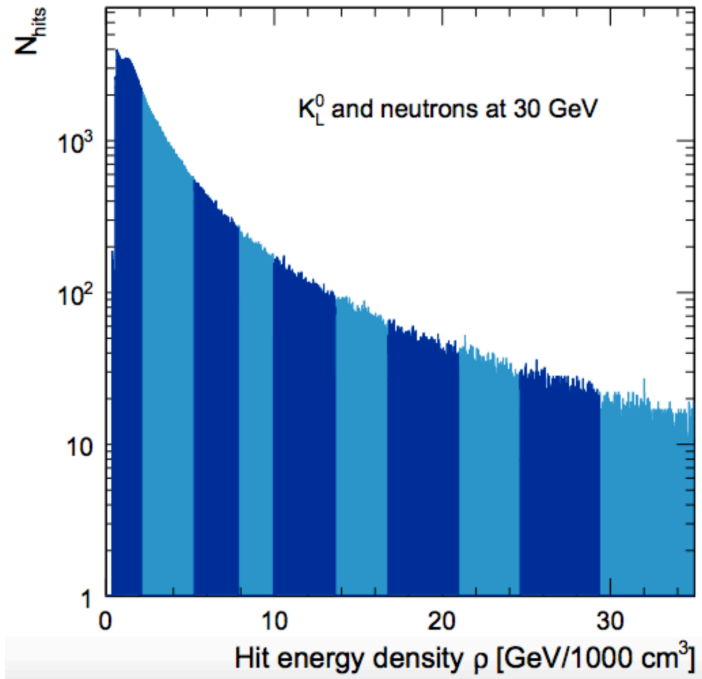


Software Compensation

- Apply weight calculated as:
- $$\omega(\rho) = p_1 \cdot \exp(p_2\rho) + p_3$$

$$p_1 = p_{10} + p_{11}\times E + p_{12}\times E^2$$
$$p_2 = p_{20} + p_{21}\times E + p_{22}\times E^2$$
$$p_3 = \frac{p_{30}}{p_{31} + e^{p_{32}\times E}}$$





- There are nine parameters to calculate the weight
- These parameters have to be optimized

Software Compensation Training

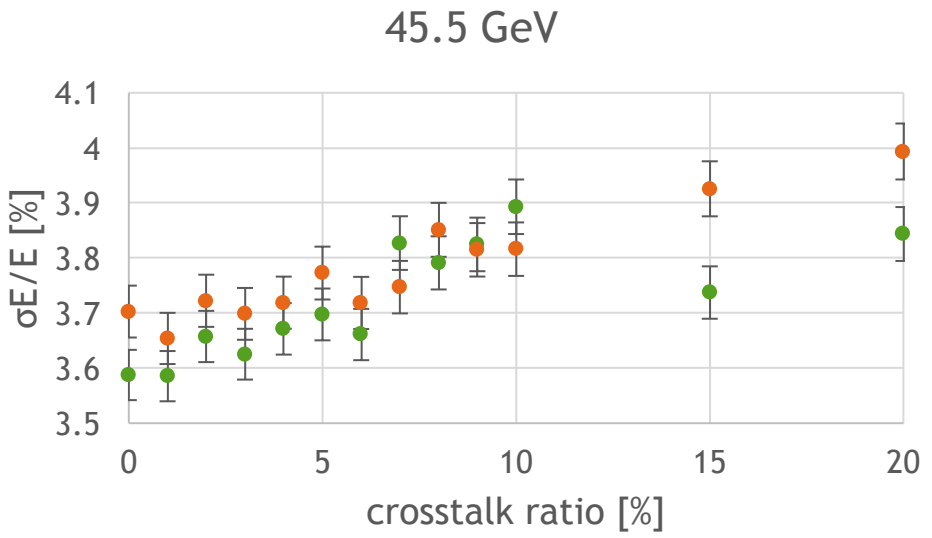
- Previous result was achieved using standard software compensation parameters
  - Optimized with another setup, without any crosstalk

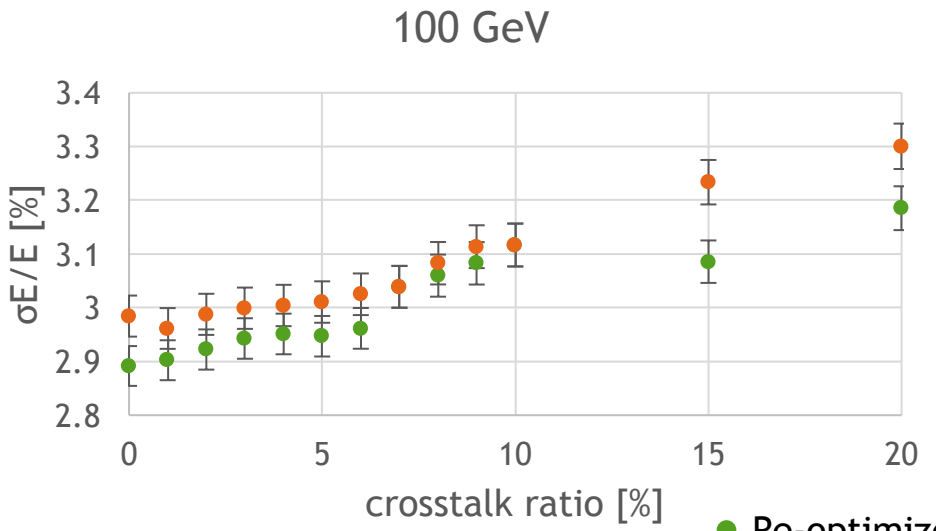
- The software compensation training needs 10 – 100 GeV neutral hadrons
- The optimization is conducted by minimizing chi square function

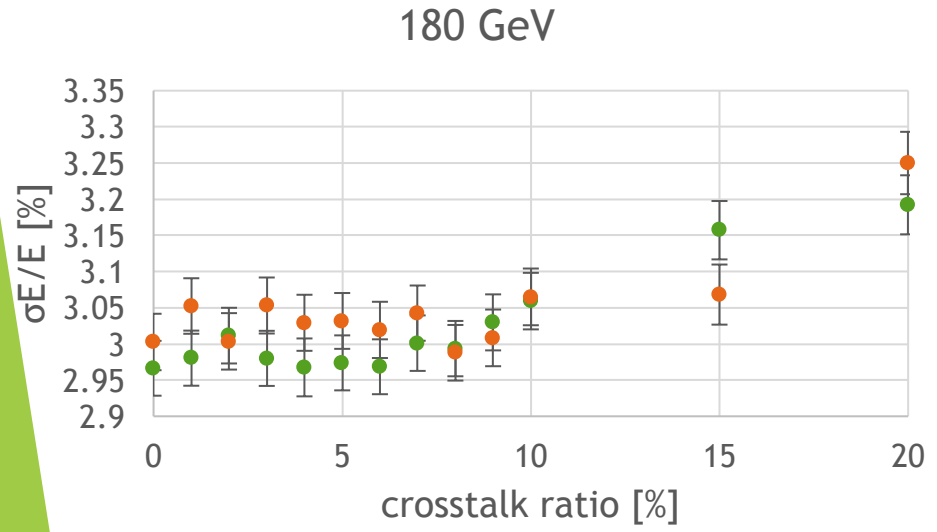
$$\chi^2 = \sum \frac{(E_{reco} - E_{true})^2}{(0.5)^2\, E_{true}}$$

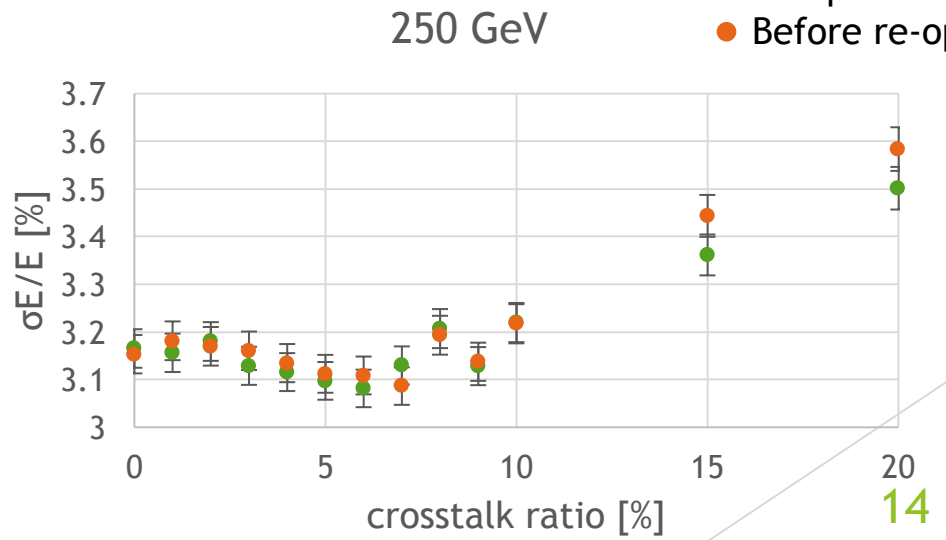
- Optimized the parameters for each crosstalk energy fraction individually
  - Thanks to Steven Green (Cambridge)

SC Optimization results







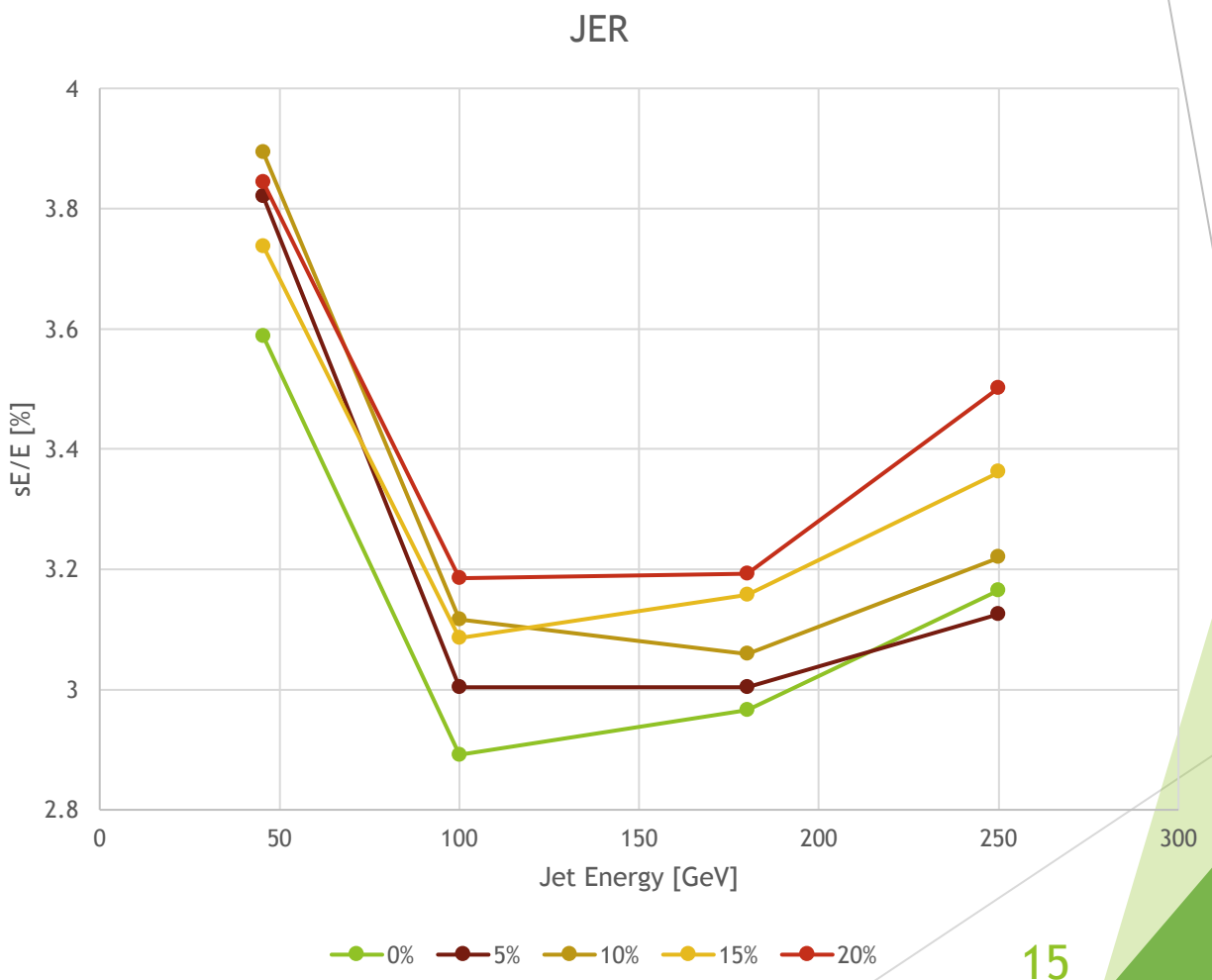


- Re-optimized
- Before re-optimization

Effect on JER is greatly suppressed at large crosstalk in low energy jet

Jet Energy Resolution with Crosstalk

- Small energy jet:
  - Small crosstalk largely affect the resolution
  - But the effect would soon saturate
- Large energy jet:
  - Small crosstalk do not much worsen the resolution
  - Badly affected when the crosstalk is large



Summary

- For some alternative design for ILD AHCAL active layers there might be a significant increase of optical crosstalk between tiles
- Investigated the effect of crosstalk on the detector performance through simulation
- Calibration of the analyzer and software compensation optimization has done
- As a result, effect on resolution depends on jet energy and extremely high crosstalk greatly worsen the jet energy resolution, but up to 4-6% the crosstalk do not much affect

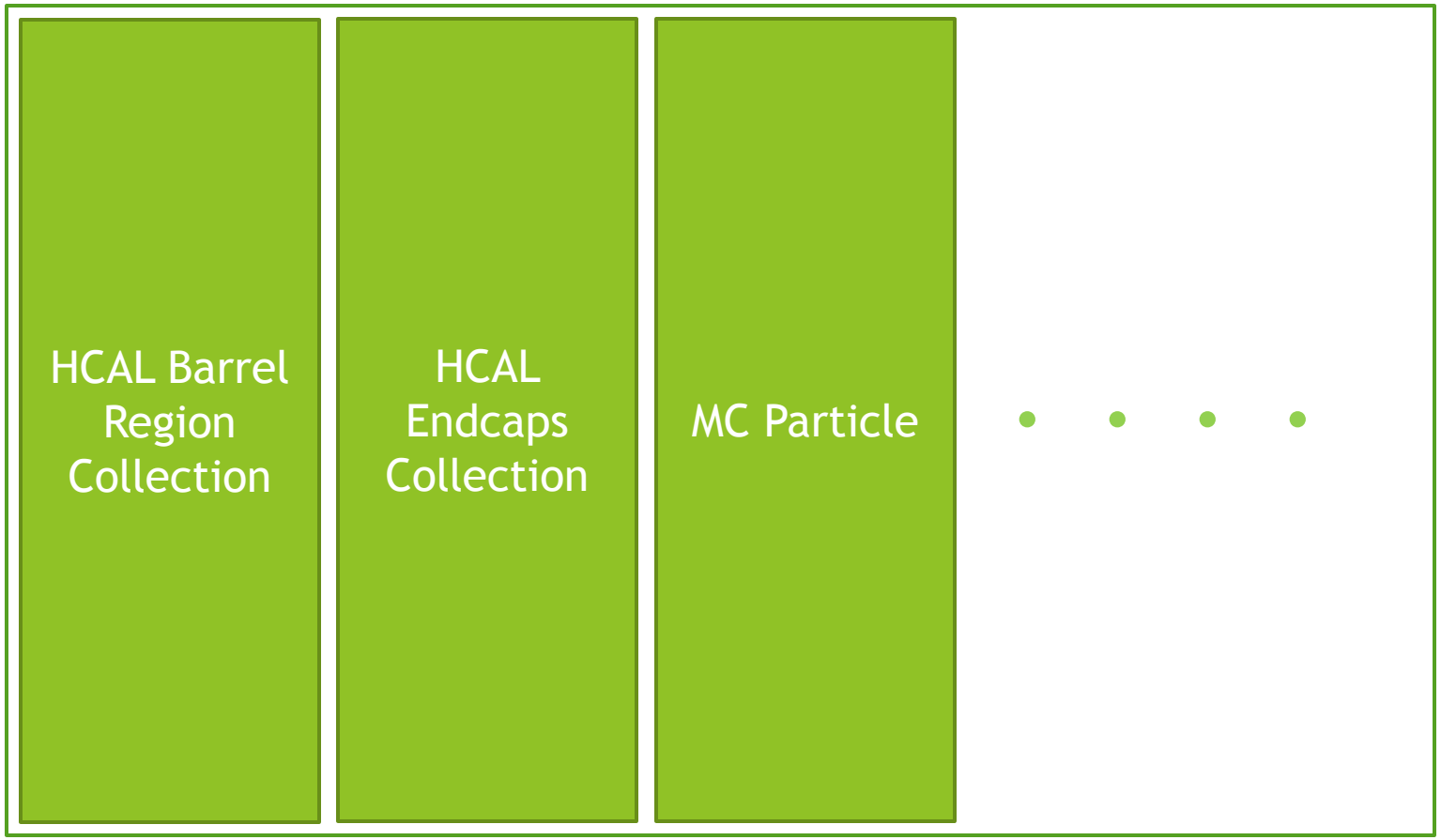
Prospects

- More realistic crosstalk
  - Random crosstalk
  - Depending on particle hit position
  - Secondary crosstalk
  - Measure the crosstalk with actual tiles
- Try to mitigate the effect of crosstalk by improving reconstruction process

THE END

Backups

Event (generated by a simulator)



Collection contents

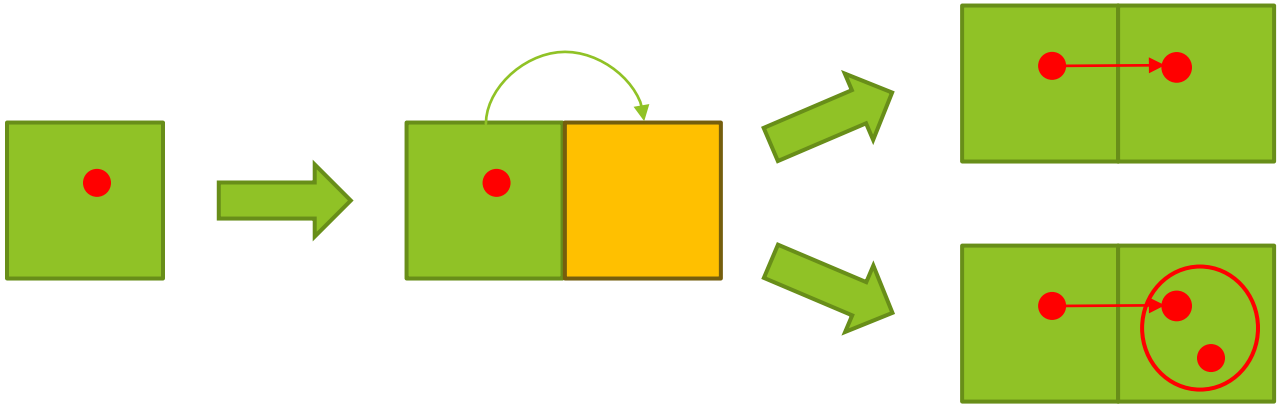
HCAL Barrel Region Collection

- Spatial Position (X,Y,Z)
- Cell Indices system, module, layer, x, y, etc.
- Energy
- Contributing particles (MC)

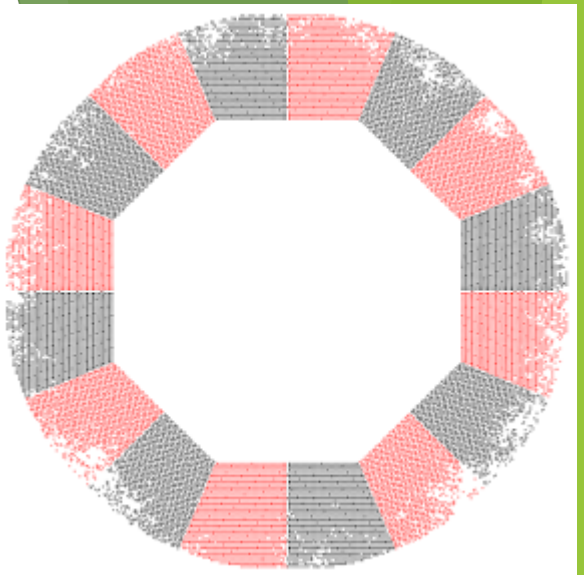
× nHits

Algorithm

- Take one hit in the event
- Calculate the cell indices and the spatial positions of neighboring cells
- Then, if there is no hit on the neighboring cell, generate a new hit with some energy fraction (like 5% or so)
- And if the neighboring cell already has a hit, add as the form of energy contribution

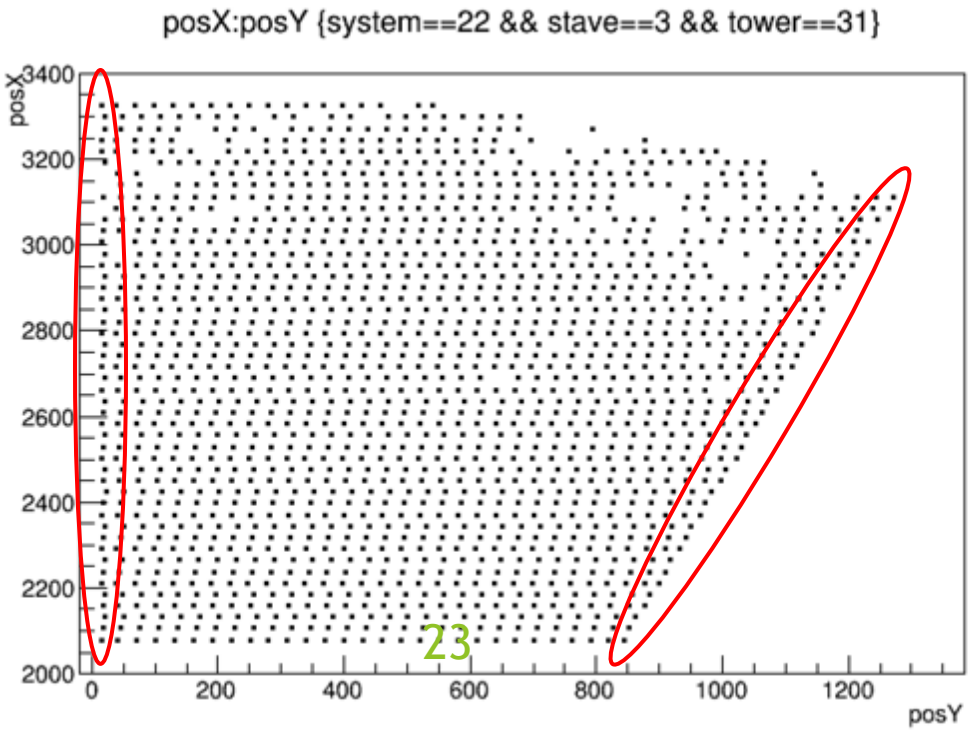


Some difficulty



- The spatial position of neighboring cell was not obvious
  - For example, in HCAL Barrel, the distance along the x-y surface is 30 mm
  - but the distance along the z axis is 30.3248 mm
  - Also the at the both edge of each module, some irregular
  - value is appearing (a bit shorter than 30 mm)

- So I just checked all the spatial alignment of the cells
- and wrote them explicitly in my code
  - (So the code is not stable for detector design changes)



Particle Flow Algorithm

- ILD is going to make use of Particle Flow Algorithm (PFA) for jet energy resolution improvement
- Hadron jets consist of many neutral and charged hadrons, photons, leptons
- PFA is to distinguish each particle in a jet and measure the particle energies with the most appropriate detector
- Cover the rather poor resolution of HCAL with ECAL and tracking detector
- The calorimeter must have high granularity for particle separation