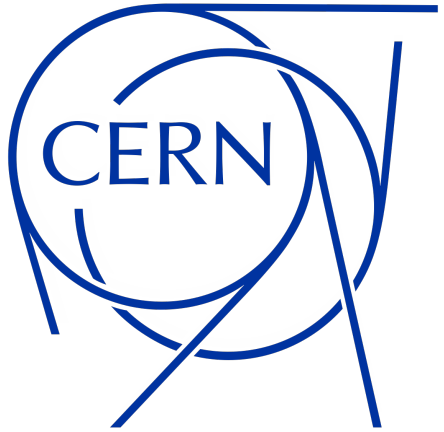

Reconstruction Tools in Key4hep

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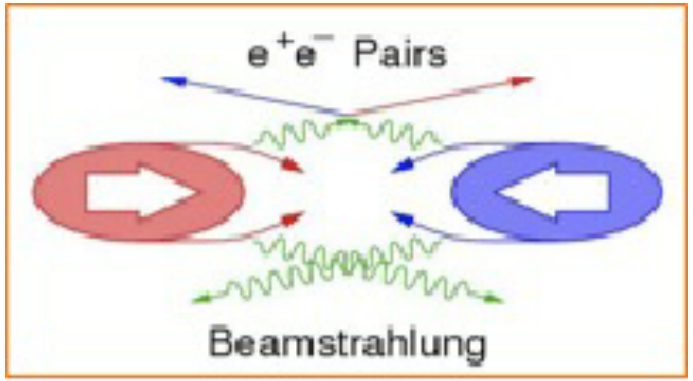
10 Oct 2024

Key4hep

- Key4hep project offers a flexible framework that allows different experiments to benefit from its synergy
- Full simulation studies essential to estimate physics reach
- Main goal: Developing optimal tools for reconstruction
  - Important to correctly treat beam backgrounds
  - Sophisticated particle flow clustering algorithms for optimal jet energy resolutions

Photon-Photon Interactions at e^+e^- colliders

- e^+e^- beams are accompanied by real and virtual photons
- Photons interact simultaneously with e^+e^- creating $\gamma\gamma \rightarrow$ low p_T hadrons, and coherent and incoherent pair backgrounds
- Important to overlay these backgrounds correctly on important physics events
- Number of beam backgrounds/bunch crossing depends on the beam parameters and the centre-of-mass energy
- Beam backgrounds overlaid on physics events based on Poissonian distribution

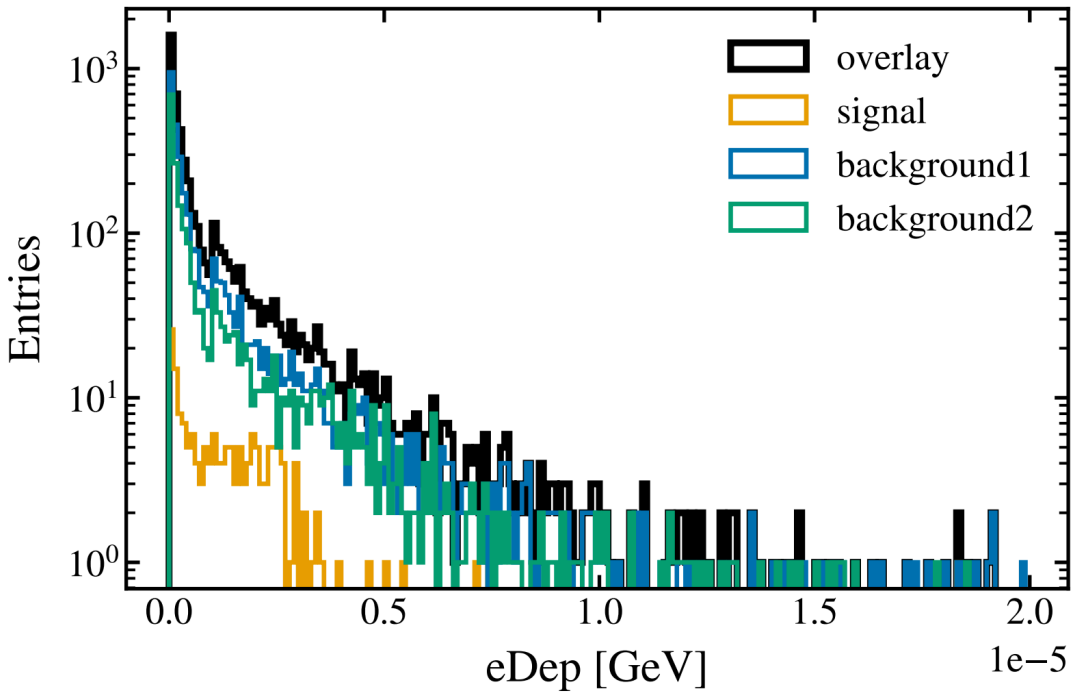


Beam background overlay algorithm in Key4hep

- The overlay algorithm from iLCSoft used during reconstruction of events
- Simulated $\gamma\gamma \rightarrow$ low pT hadron events and e^+e^- pair background events overlaid on simulated physics processes in three ways:
  - **MCParticles**: MCParticles from beam backgrounds are overlaid on MCParticles from signal
  - **SimTrackerHits**: are overlayed if they are in a certain time window
  - **SimCalorimeterHits**: are overlayed only if they have contributions in a certain time window. If a signal hit and a background hit have the same cellID, they are combined into a single hit
- The OverlayTiming processor from iLCSoft ported to Gaudi by J-M Carceller

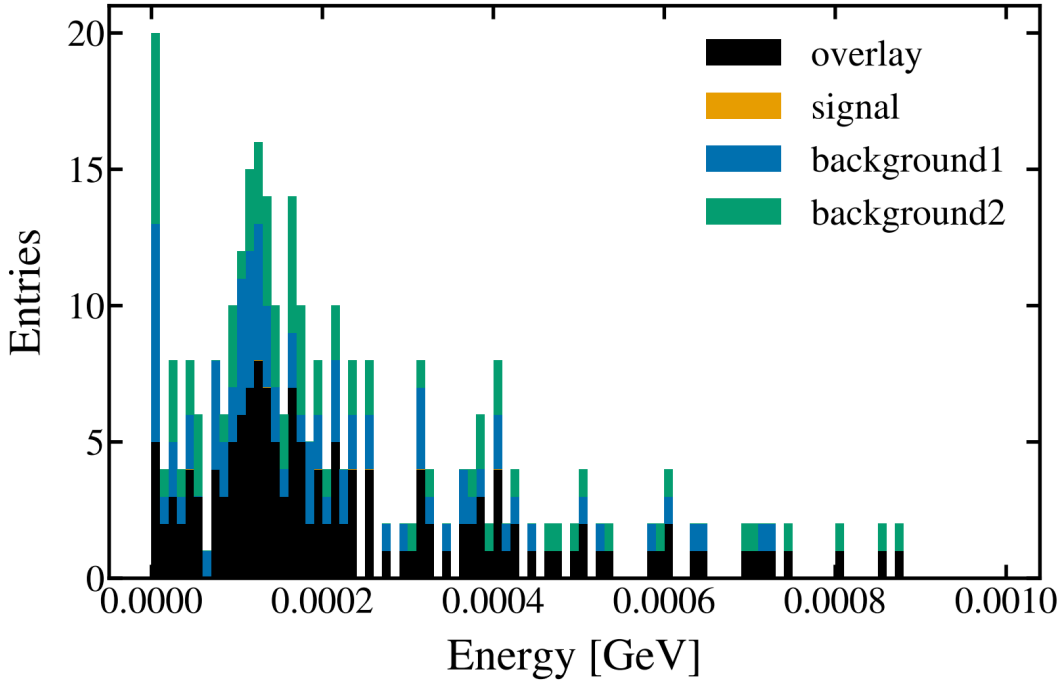
Overlay on SimTrackerHit and SimCaloHits

SimTrackerHit



signal	background1	background2	sum	overlay
1	22	23	46	21

SimCalorimeterHit



signal	background1	background2	sum	overlay
0	86	78	164	149

Native Overlay algorithm in Key4hep

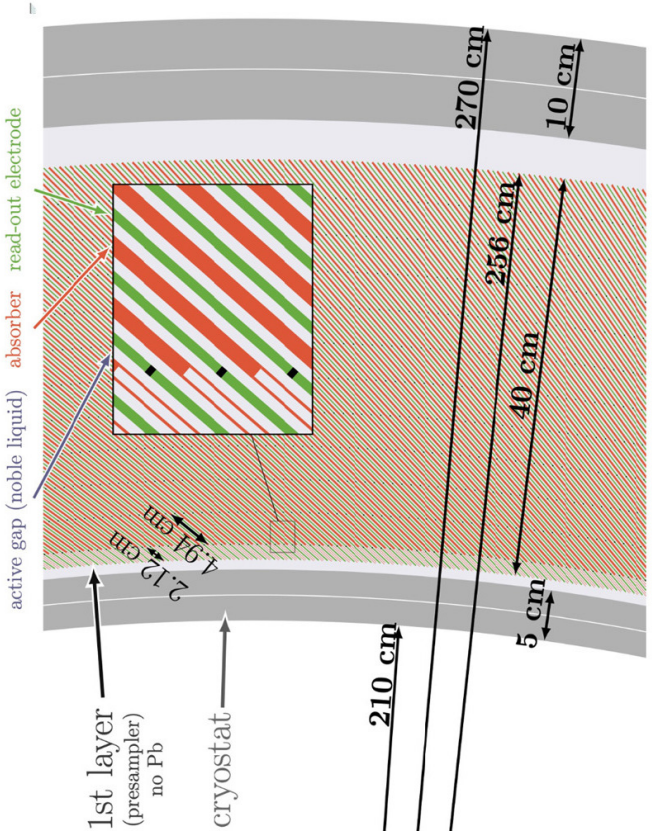
- For MCParticles and SimTrackerHits, there is an isOverlay() method that tells us if they come from background or signal
- Relations in the new objects point to the new objects: a SimTrackerHit from signal will point to the corresponding MCParticle in the overlayed collection, the same for background
- Ported OverlayTiming Gaudi algorithm from iLCSoft (J-M Carceller): Currently PR in Key4hep/k4reco
- Background Overlay algorithm ready to be tested (and reviewed)
- Looks OK so far, still need to check some details

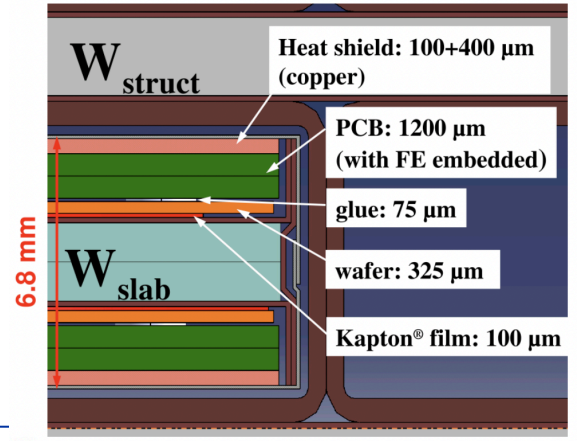
Particle Flow Algorithm

- Events correctly processed with overlaying beam backgrounds correctly facilitating further optimisation of the detector
- Important ingredient for performance of future Higgs factory experiments: particle flow reconstruction for optimal jet energy resolutions
- Pandora particle flow algorithm (PandoraPFA) developed to study particle flow calorimetry
  - PandoraPFA combines the tracking information with hits in high granularity calorimeters
  - Reconstruction of every individual particles in the event
  - DDMarlin Pandora is the Marlin integration of Pandora to iLCSoft framework to study particle flow at high granularity CALICE calorimeters

Geometry information for PandoraPFA

- DDMarlinPandora designed with high granularity CALICE sandwich calorimeters
- LAr calorimeter has a very different structure : an ensemble of different materials in a cell varying in density and homogeneity
- Density of material also varies from the inner radius to the outer radius of the barrel
- Moreover, the inclination of the segments play a role
- Challenging to calculate radiation length or interaction length for LAr



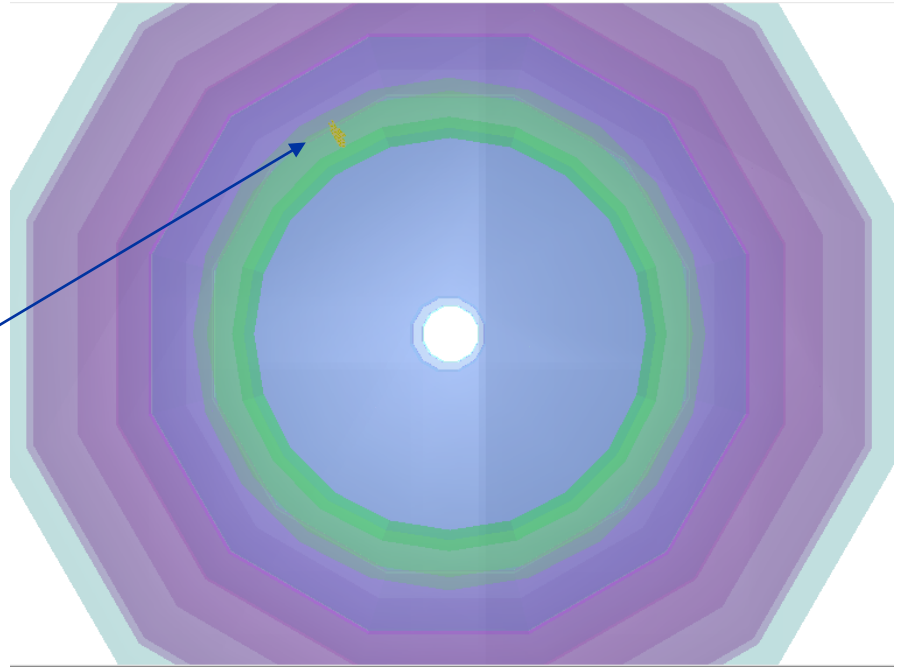


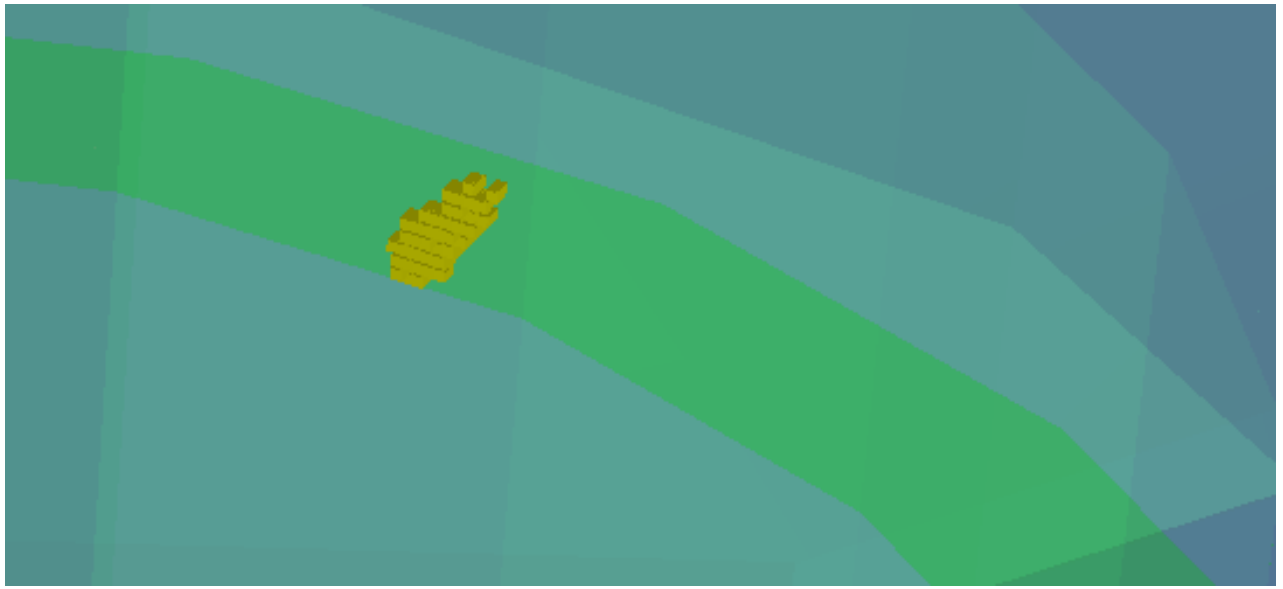
Material Manager

- Such information for the LAr calorimeter is obtained in a more dynamic way
- **`MaterialManager`** is a tool from DD4hep that helps extracting the necessary information between arbitrary space points
- **`MaterialManager`** returns the list of materials and their thickness along the vector
- By averaging the material between the arbitrary points material properties of the averaged material was extracted
- Crosscheck: The sum of the radiation lengths across the layers sums up to 22 X_0 as expected for the calorimeter
- This approach allows for dynamic determination of material properties irrespective of the detector model

Pandora clusters in LAr

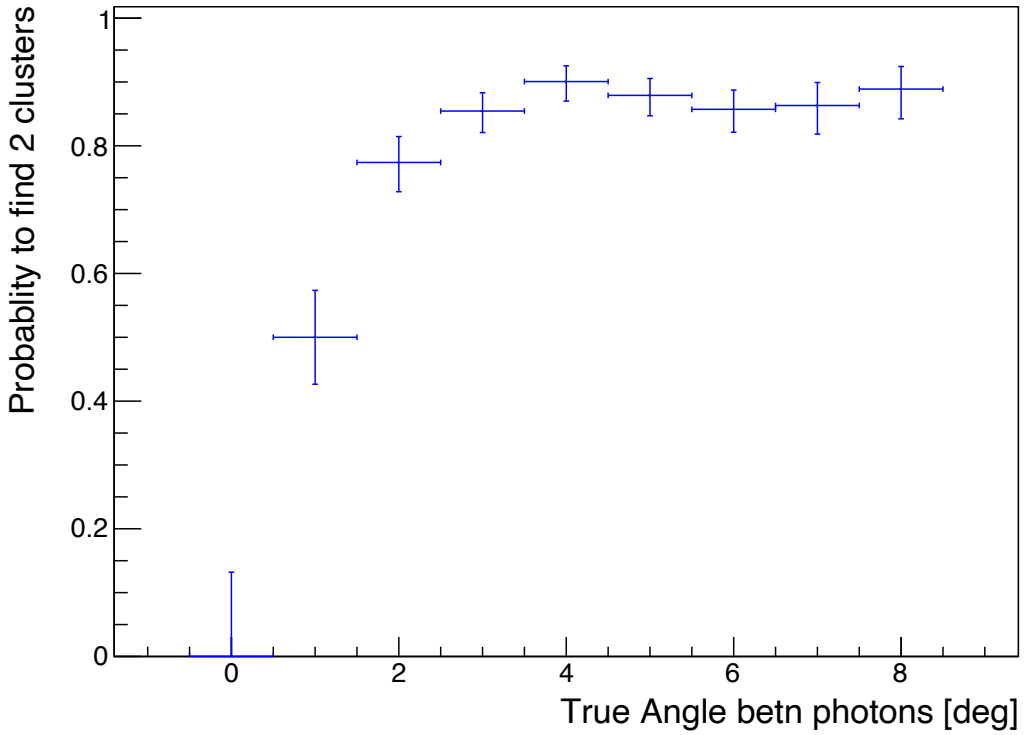
- 500 events of photons using a particle gun was simulated at an energy of 10 GeV for the CLD_LAr detector model
- By running reconstruction with all the digitized hit collections provided to Pandora, Pandora particle flow objects (PandoraPFO's) from LAr calorimeter could be observed 🥳





Probability to find two photon clusters

- To optimise the cluster reconstructions - study how well the photon clusters can be separated
- The cell size of ALLEGRO- LAr is 2 x 2 cm^2
- The Molière radius for LAr calorimeter is 4cm which is much bigger than the CALICE calorimeters (9mm)
- The photons need to be at least 5-6 cms apart for a high probability to be separately clustered
- Work in progress



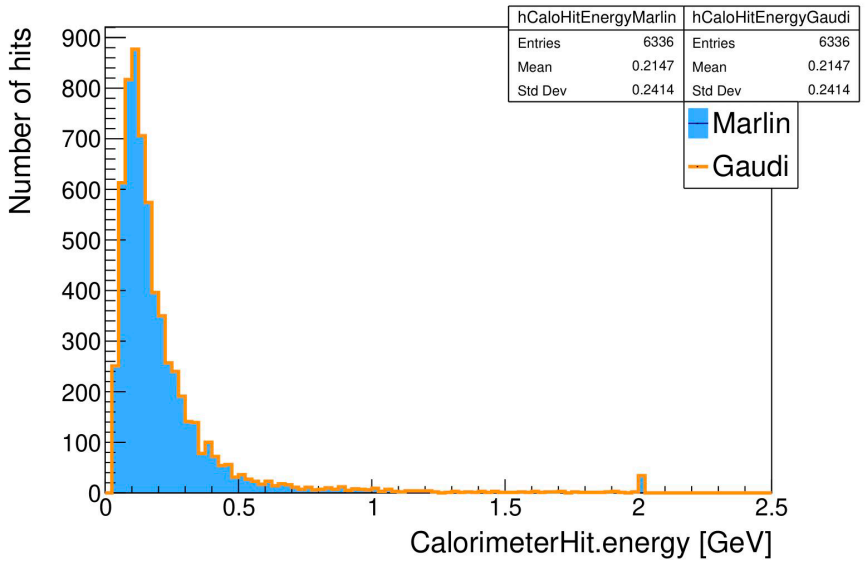
Porting of DDMarlinPandora

- DDMarlinPandora a package in iLCSoft with multiple processors
- To integrate into native Key4hep it is being ported to Gaudi
- Started with two digitisers: DDSimpleMuonDigi (muons) and DDCaloDigi(ECal, HCal) parts of DDMarlinPandora
- Largely ported by S.Sasikumar and, finalised and validated by K.Kostova
  - DDSimpleMuonDigi: A simple processor for the digitisation of muons
  - DDCaloDigi: More complex processor for digitisation of particles in ECal and HCal
- DDSimpleMuonDigi already integrated to k4GaudiPandora and a PR is open for DDCaloDigi close to be merged

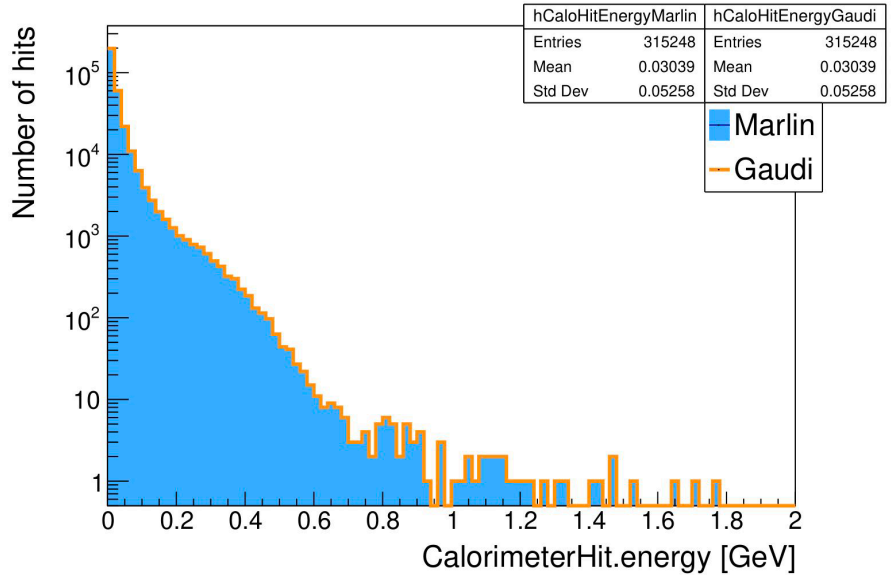
Validation of digitisers in DDMarlinPandora

- 1000 events of muons and photons simulated for 10 GeV using particle gun (K. Kostova)
- Same simulated input file used for digitising using Marlin processors and ported Gaudi algorithms
- The distributions well overlapped on each other - porting successful
- The final DDPandoraPFA still needs to be ported

DDSimpleMuonDigi



DDCaloDigi



Summary

- Key4hep actively developing and integrating reconstruction tools
- Overlay algorithm successfully ported and ready to be used
- Dynamic ways to obtain important information about the material properties of the calorimeters model-independently
- Two digitisers (DDSimpleMuonDigi and DDCaloDigi) of DDMarlinPandora successfully ported and validated

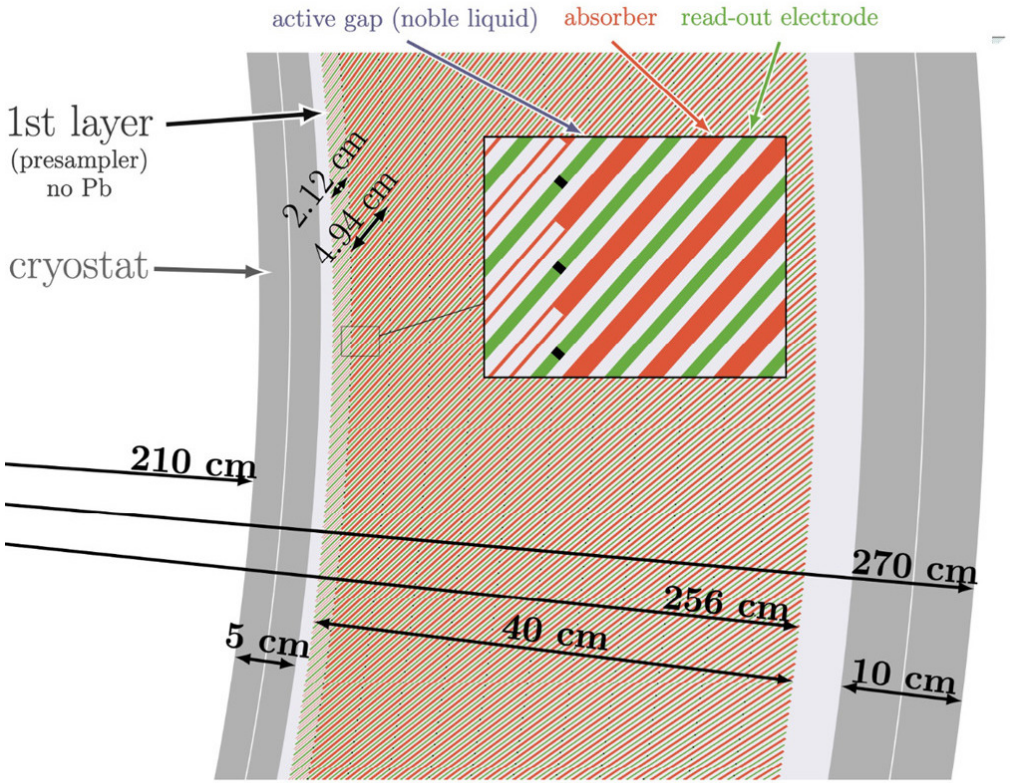
Acknowledgement:

This work is funded by CERN strategic R&D Programme on Technologies for Future Experiments

BACKUP SLIDES

The Noble Liquid Argon Calorimeter

- The FCC detector - ALLEGRO has chosen the Liquid Argon (LAr) calorimeter as its Electromagnetic calorimeter
- This calorimeter consists of liquid argon as the sensitive material with steel/Pb absorbers and readouts inclined at an angle of 50 degrees wrt the radius
- The LAr calorimeter has 12 different layers
- Makes a good candidate studying Pandora PFA on a completely different detector model



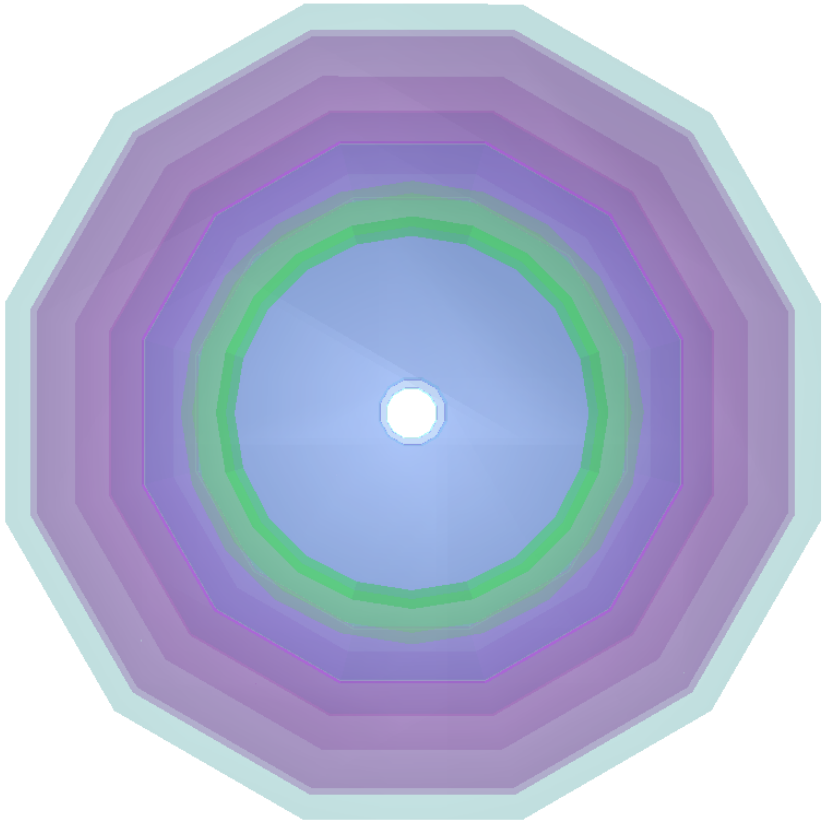
Pandora PFA and Layered Calorimeter Data

- PandoraPFA uses material properties e.g. radiation lengths and interaction lengths to determine the depth of the particle shower in the detector
- Particle flow clustering with Pandora uses the extensions attached to the detector geometries to provide the properties of the calorimeter
- The **`DD4hep::rec::LayeredCalorimeterData`** provides details like radiation length, interaction length and dimensions to the reconstruction algorithms

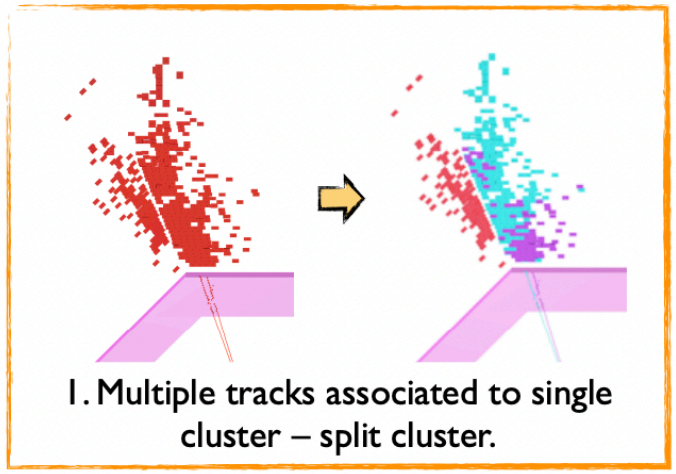
```
dd4hep::rec::LayeredCalorimeterData::Layer caloLayer;
caloLayer.distance = rad_first;
caloLayer.inner_nRadiationLengths   = value_of_x0/2.0;
caloLayer.inner_nInteractionLengths = value_of_lambda/2.0;
caloLayer.inner_thickness           = difference_bet_r1r2/2.0;
```

Geometry Adaptations to CLD

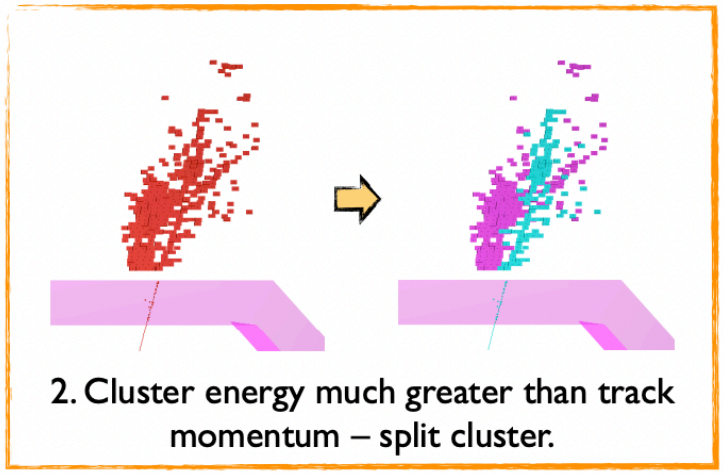
- Challenge - no full simulation for ALLEGRO in Key4hep yet
- Need tracks for Pandora PFA
- Using CLD detector as a base for full simulation and reconstruction a detector model as `CLD_o4_v05` was created with LAr calorimeter as the ECAL
- The LAr ECal is almost three times the size of the CLD ECAL
- To include LAr instead of the CLD ECAL the geometry of the detector needs to be adapted to avoid the overlaps between the subdetectors
- HCAL, Solenoid and the Yoke moved out further to accommodate LAr in the detector



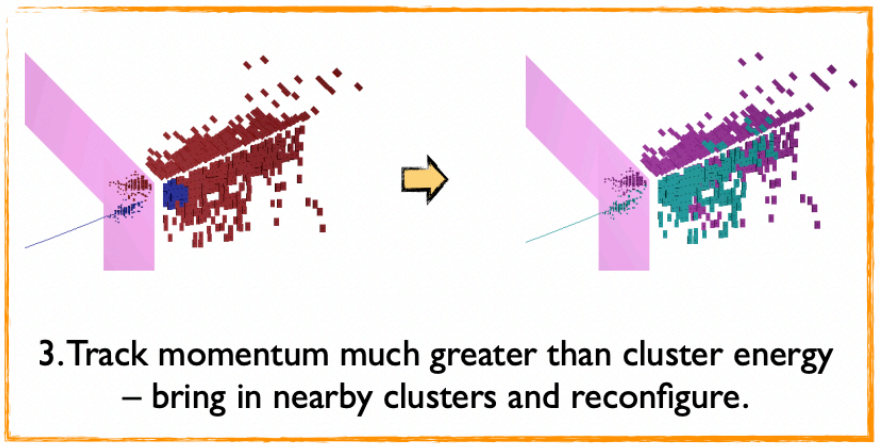
Reclustering Strategies



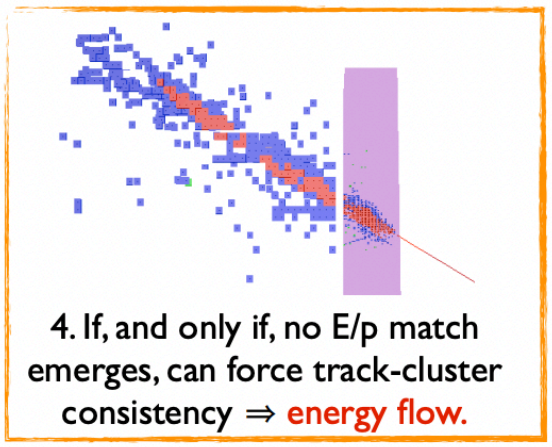
1. Multiple tracks associated to single cluster – split cluster.



2. Cluster energy much greater than track momentum – split cluster.

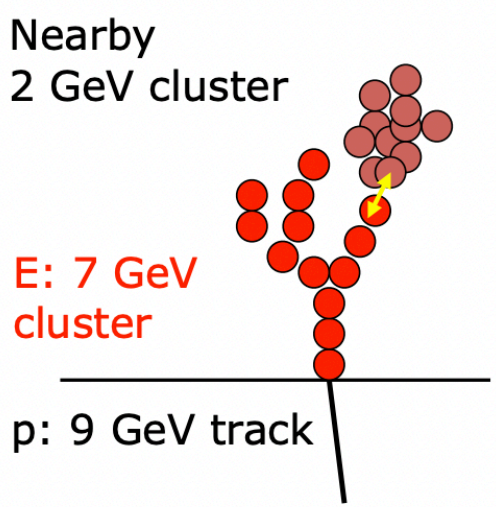


3. Track momentum much greater than cluster energy – bring in nearby clusters and reconfigure.

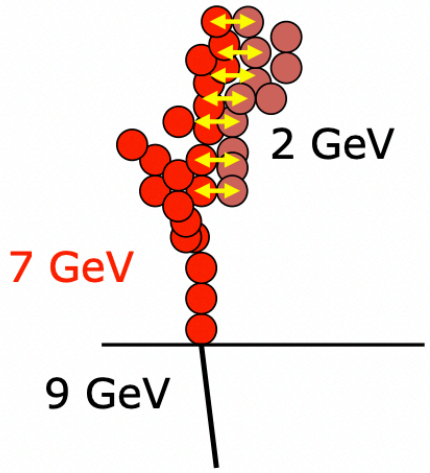


4. If, and only if, no E/p match emerges, can force track-cluster consistency ⇒ energy flow.

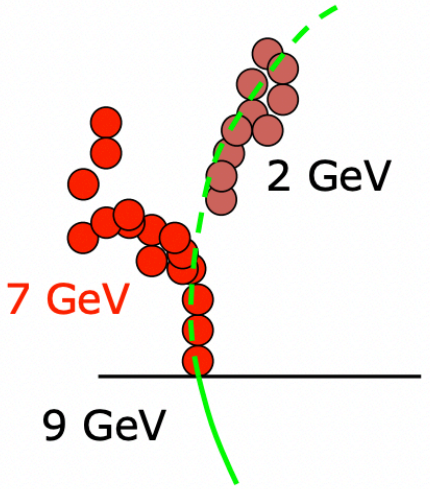
Evidence of association:



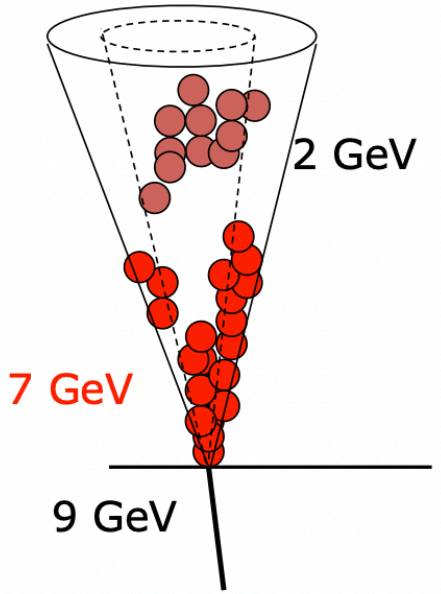
Small distance of closest approach



Multiple layers in close contact



Small distance to track extrapolation



Large fraction of energy in cone