Reconstruction Tools in Key4hep

Swathi Sasikumar, Andre Sailer, Juan-Miguel Carceller

10 Oct 2024

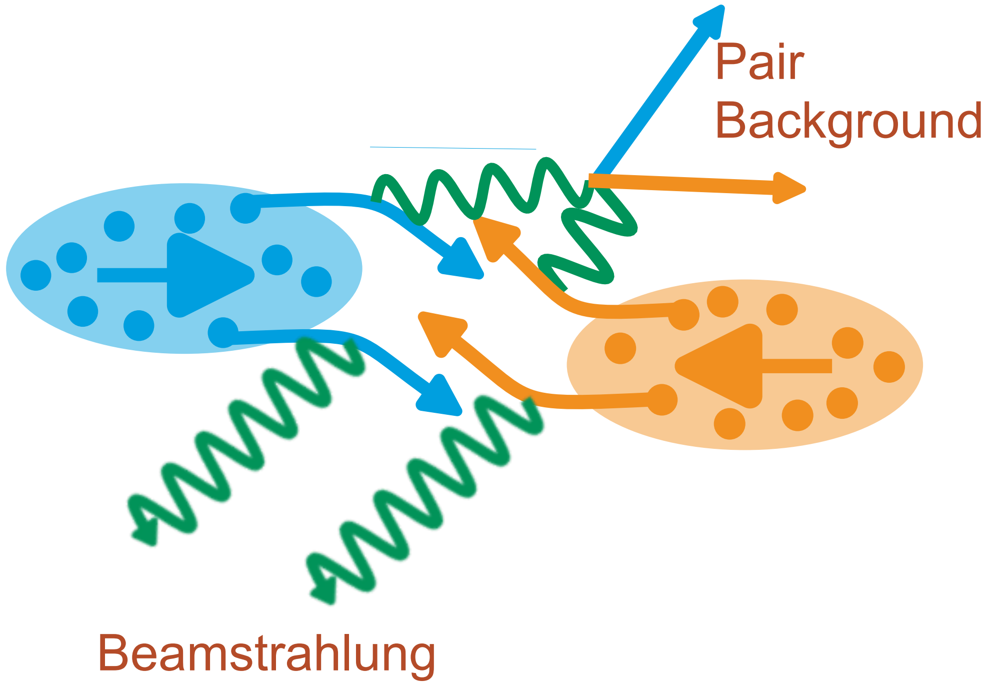
3rd ECFA Workshop on Higgs, Top and electroweak Factories

Key4hep

- Key4hep project offers a flexible framework that allows different experiments to benefit from its synergy
- Main goal: Share and develop optimal tools for generation, simulation, reconstruction and analysis
- Today's Focus:
  - Overlay algorithm to correctly treat beam backgrounds
  - Sophisticated particle flow clustering algorithms for optimal jet energy resolutions
  - Porting and validation of digitisation algorithms from ILCSoft framework to Key4hep native Gaudi framework

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

- e^+e^- beams are accompanied by real and virtual photons
- Number of beam backgrounds/bunch crossing depends on the beam parameters and the centre-of-mass energy
- These photons happen simultaneously with e^+e^- processes creating overlay backgrounds ($\gamma\gamma$ backgrounds, e^+e^- pair bkg)
- Important to overlay these backgrounds correctly on important physics events



Beam background overlay algorithm in Key4hep

- The overlay algorithm from iLCSoft framework used with k4MarlinWrapper
- Overlay background events and hard-interaction physics events simulated separately
- Background events overlaid on the physics events during reconstruction of the events using three input collections:
  - **MCParticles**: MCParticles from beam backgrounds are overlaid on MCParticles from signal
  - **SimTrackerHits**: are overlaid if they are in a certain time window
  - **SimCalorimeterHits**: are overlaid 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

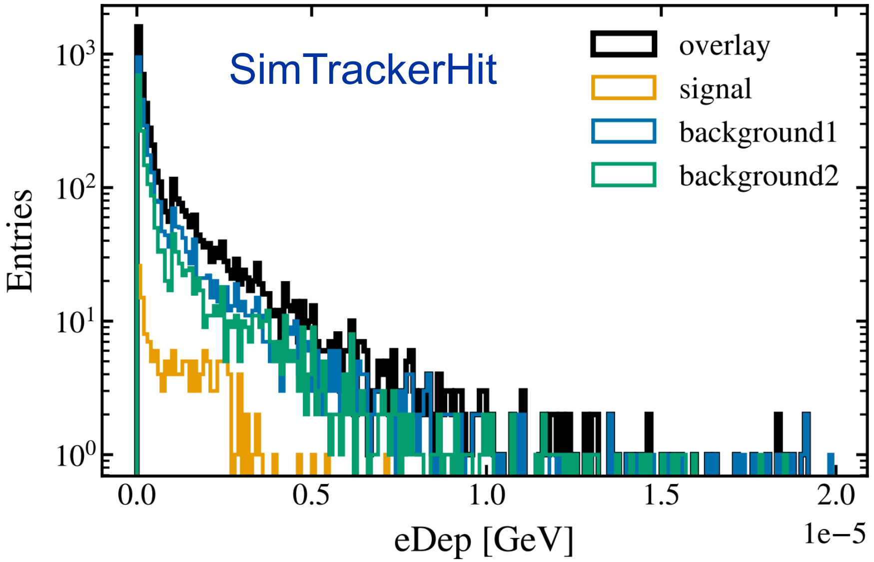
Steering File in native Key4hep

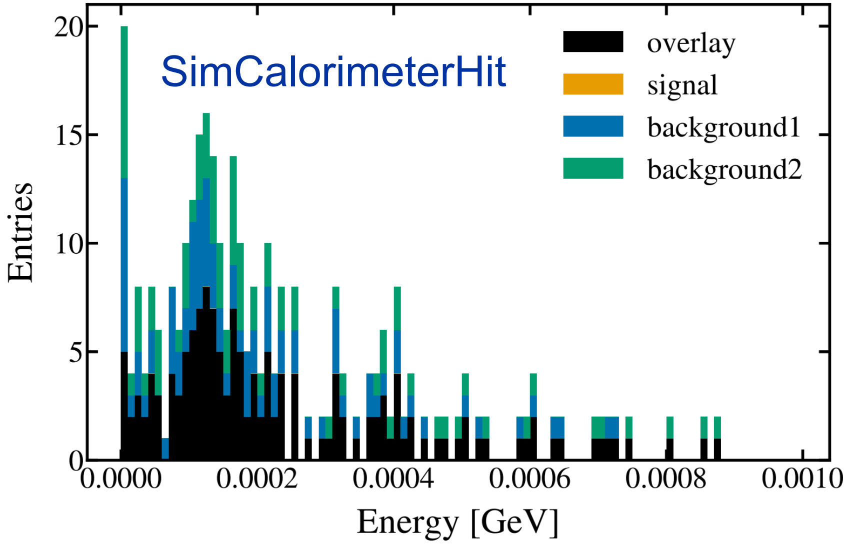
```python
from k4FWCore import ApplicationMgr
from k4FWCore import IOSvc
from Configurables import EventDataSvc
from Configurables import OverlayTiming
from Configurables import UniqueIDGenSvc

id_service = UniqueIDGenSvc("UniqueIDGenSvc")
eds = EventDataSvc("EventDataSvc")

iosvc = IOSvc()
iosvc.input = "input.root"
iosvc.output = "output_overlay.root"

overlay = OverlayTiming()
overlay.MCParticles = ["MCParticle"]
overlay.SimTrackerHits = ["VertexBarrelCollection", "VertexEndcapCollection"]
overlay.SimCalorimeterHits = ["HCalRingCollection"]
overlay.CaloHitContributions = ["CaloHitContributionsCollection"]
overlay.OutputSimTrackerHits = ["NewVertexBarrelCollection", "NewVertexEndcapCollection"]
overlay.OutputSimCalorimeterHits = ["NewHCalRingCollection"]
overlay.OutputCaloHitContributions = ["NewCaloHitCollection"]
# overlay.StartBackgroundEventIndex = 0
overlay.BackgroundFileNames = [
    ["/Overlay/background1.root"],
    ["/Overlay/background2.root"],
]
overlay.TimeWindows = {"MCParticle": [0, 23.5], "VertexBarrelCollection": [0, 23.5], "VertexEndcapCollection": [0, 23.5], "HCalRingCollection": [0, 23.5]}

ApplicationMgr(TopAlg=[overlay],
               EvtSel="NONE",
               EvtMax=10,
               ExtSvc=[eds],
               OutputLevel=INFO,
               )
```

- Ported OverlayTiming to Gaudi algorithm from iLCSoft (J-M Carceller)

Native Overlay algorithm in Key4hep

- Overlay algorithm sets an overlay flag for beam background particles in the MCCollection as before
- Relations in the new objects point to the new objects: a SimTrackerHit from signal will point to the corresponding MCParticle in the overlaid collection, the same for background
- Overlay algorithm merged into Key4hep/k4reco
- Background Overlay algorithm ready to be used in reconstruction chain
- Events correctly processed with overlaying beam backgrounds facilitating further optimisation of the detector





Particle Flow Algorithm

- 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 particle in the event
  - DDMarlinPandora is the Marlin integration of Pandora to iLCSoft framework to study particle flow at high granularity CALICE calorimeters
  - To integrate into Key4hep important to get Pandora work across detector model: Nobel Liquid Argon calorimeter a good candidate

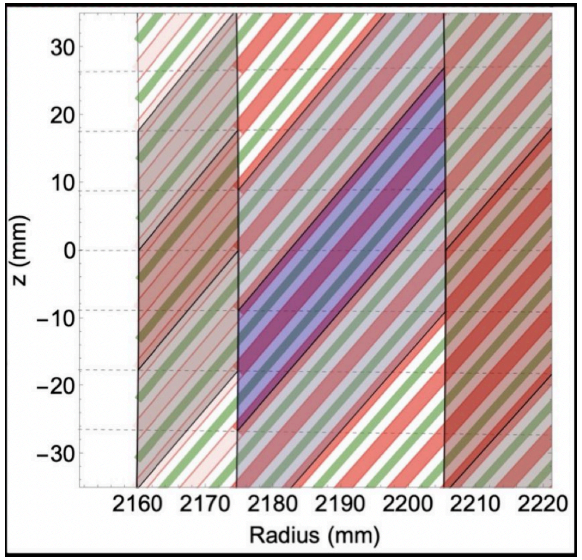
Pandora PFA and Layered Calorimeter Data

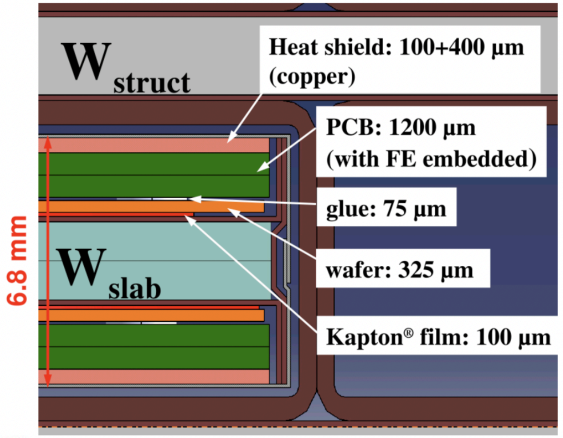
- PandoraPFA uses material properties e.g. radiation lengths and interaction lengths to determine the depth of the particle shower in the detector
- Particle flow clustering with Pandora uses the extensions attached to the detector geometries to provide the properties of the calorimeter
- The **`DD4hep::rec::LayeredCalorimeterData`** 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 information for PandoraPFA

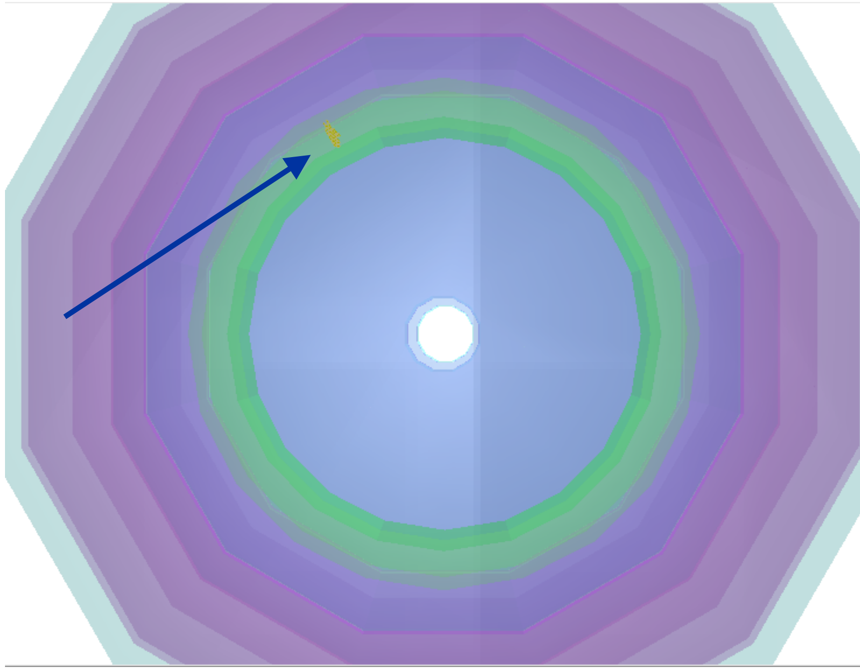
- DDMarlinPandora designed with high granularity CALICE sandwich calorimeters
- LAr calorimeter has a very different structure : an ensemble of different materials in a cell varying in density and homogeneity
- Density of material also varies from the inner radius to the outer radius of the barrel
-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





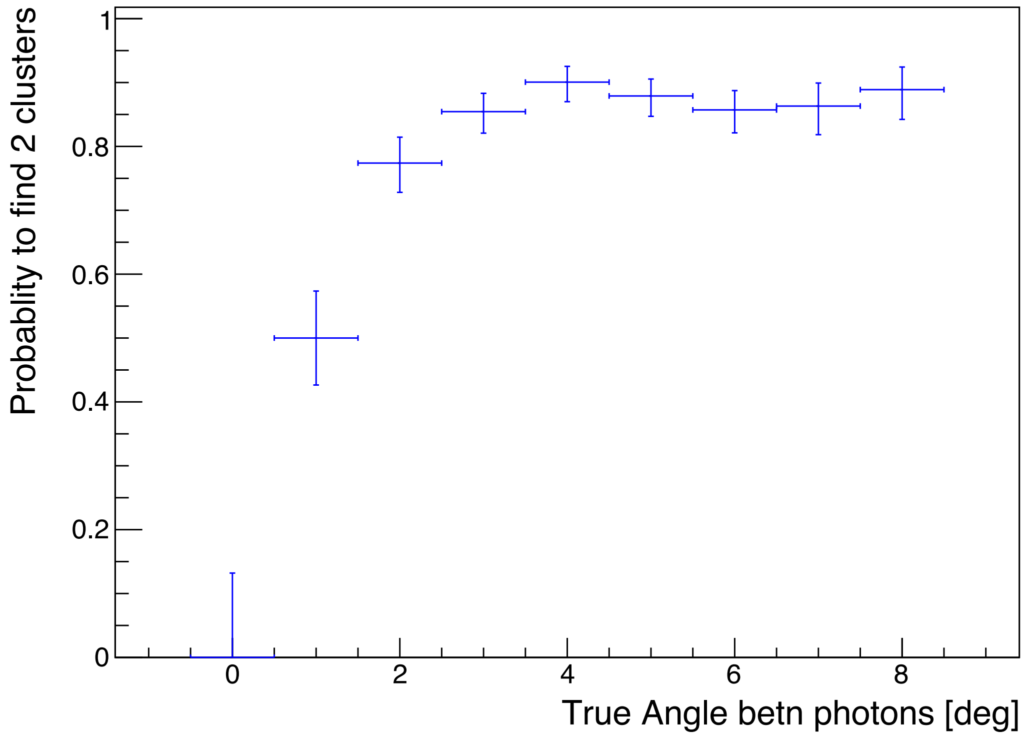
Material Manager

- 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
- This approach allows for dynamic determination of material properties irrespective of the detector model



Probability to find two photon clusters

- To optimise the cluster reconstructions - study how well the photon clusters can be separated
- 1000 events of two photons simulated using particle gun at 10 GeV for LAr ECal barrel
- 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
- The cell size of ALLEGRO- LAr ~2 x 2 cm^2
- Work in progress



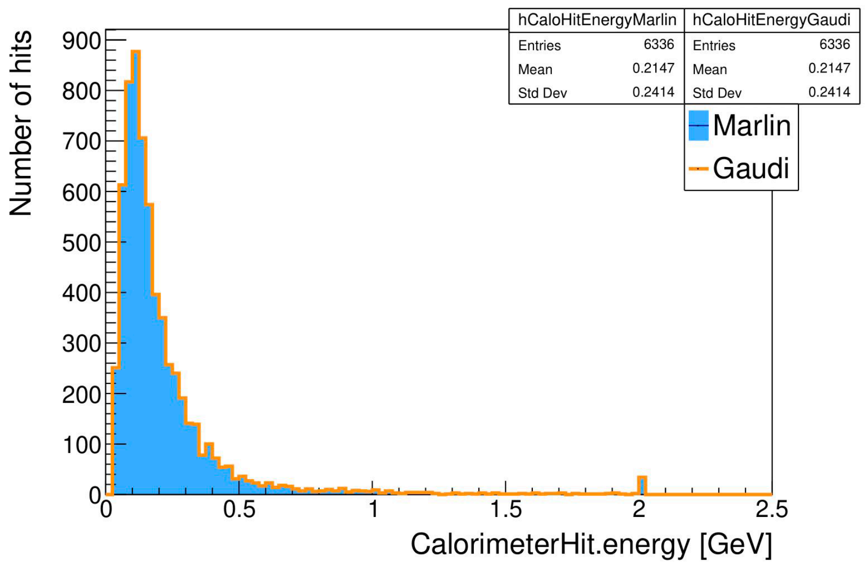
Porting DDMarlinPandora into native Key4hep

- 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
  - DDSimpleMuonDigi: A simple processor for the digitisation of muons
  - DDCaloDigi: More complex processor for digitisation of particles in ECal and HCal
- Largely ported by S.Sasikumar and, finalised and validated by K.Kostova
- DDSimpleMuonDigi already integrated to k4GaudiPandora and a PR is open for DDCaloDigi close to be merged

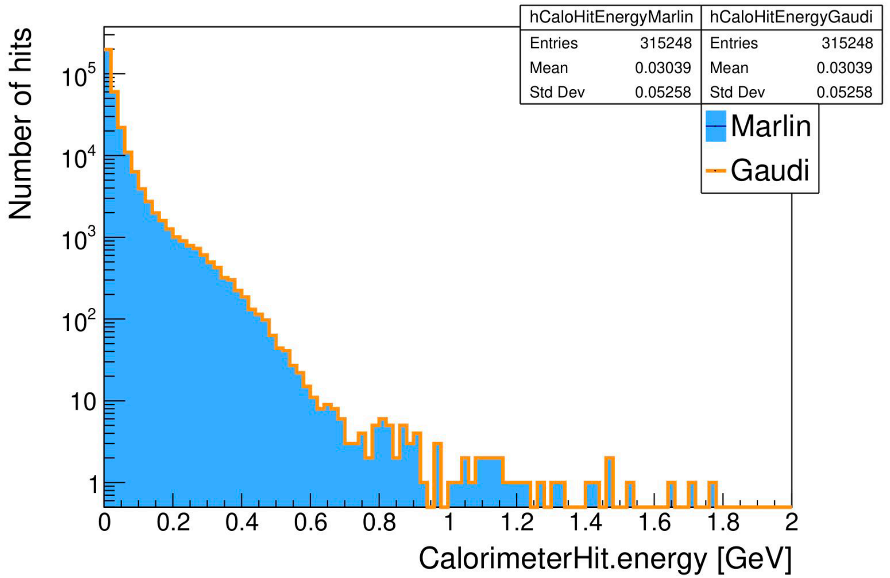
Validation of digitisers in DDMarlinPandora

- 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
- Can add PandoraPFA on any detector model irrespective of different geometries
- Two digitisers (DDSimpleMuonDigi and DDCaloDigi) of DDMarlinPandora successfully ported and validated

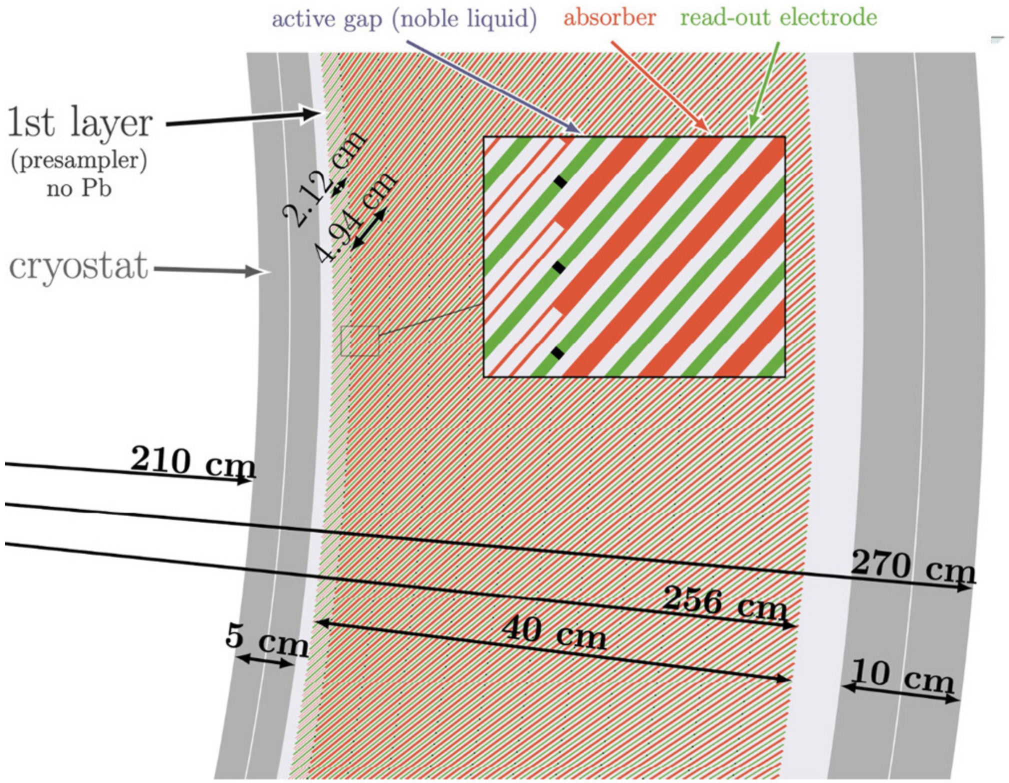
Acknowledgement:

This work benefited from support by the CERN Strategic R&D Programme on Technologies for Future Experiments. This project also received funding from the European Union’s Horizon 2020 Research and Innovation Programme under Grant Agreement No 101004761.

BACKUP SLIDES

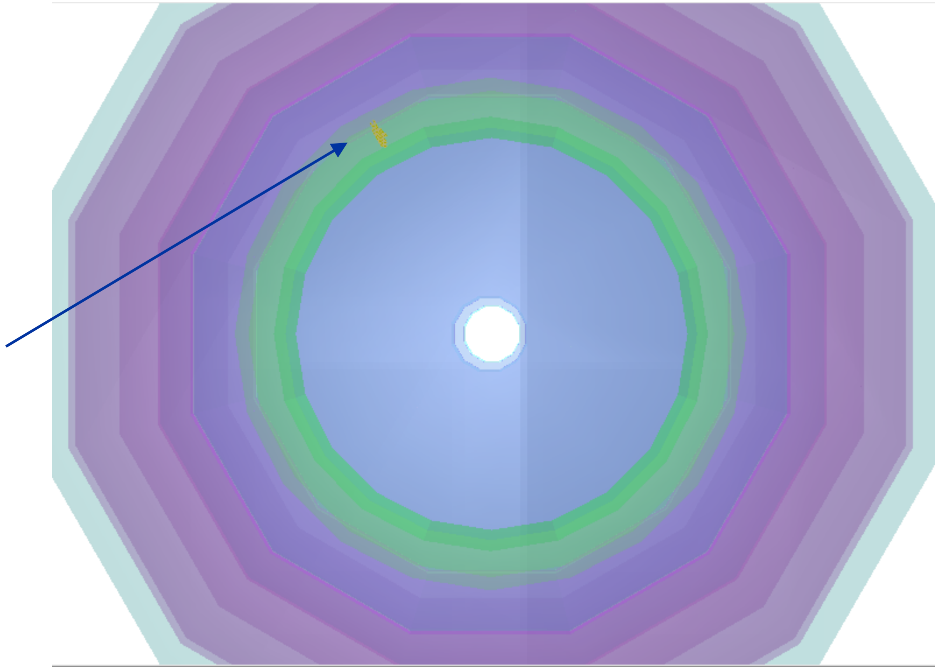
The Noble Liquid Argon Calorimeter

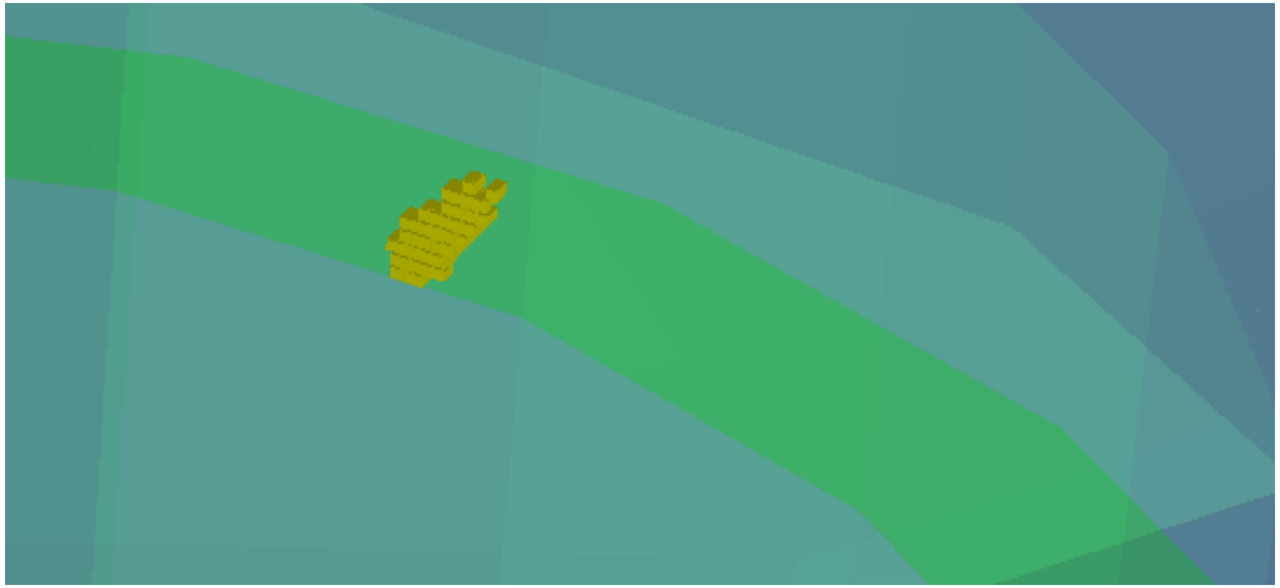
- The FCC detector - ALLEGRO has chosen the Liquid Argon (LAr) calorimeter as its Electromagnetic calorimeter
- This calorimeter consists of liquid argon as the sensitive material with steel/Pb absorbers and readouts inclined at an angle of 50 degrees wrt the radius
- The LAr calorimeter has 12 different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



Pandora clusters in LAr

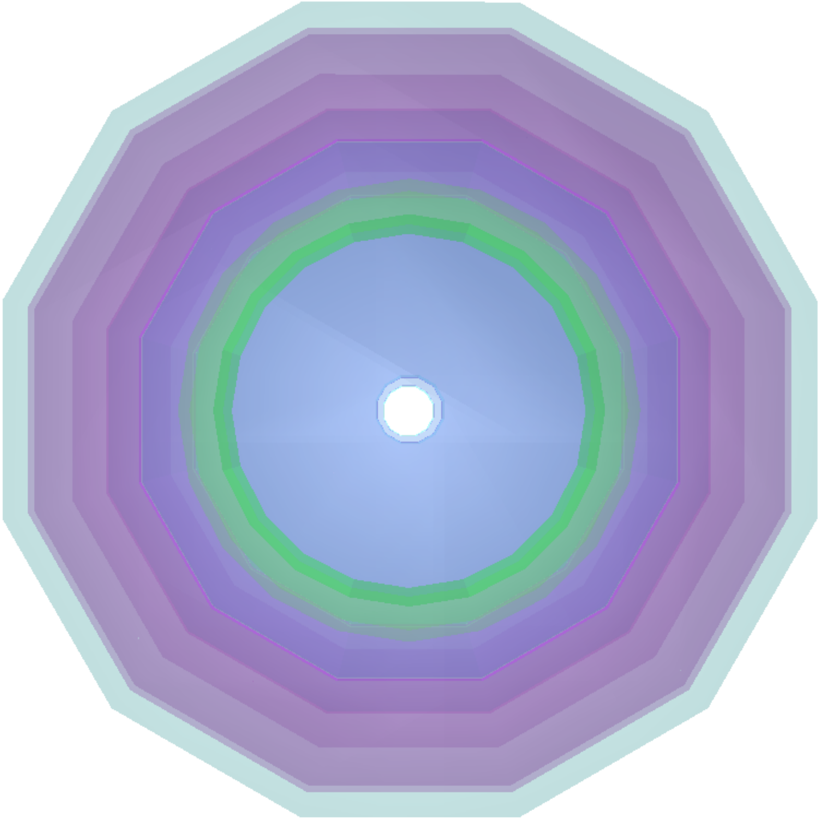
- 500 events of photons using a particle gun was simulated at an energy of 10 GeV for the CLD_LAr detector model
- By running reconstruction with all the digitized hit collections provided to Pandora, Pandora particle flow objects (PandoraPFO's) from LAr calorimeter could be observed



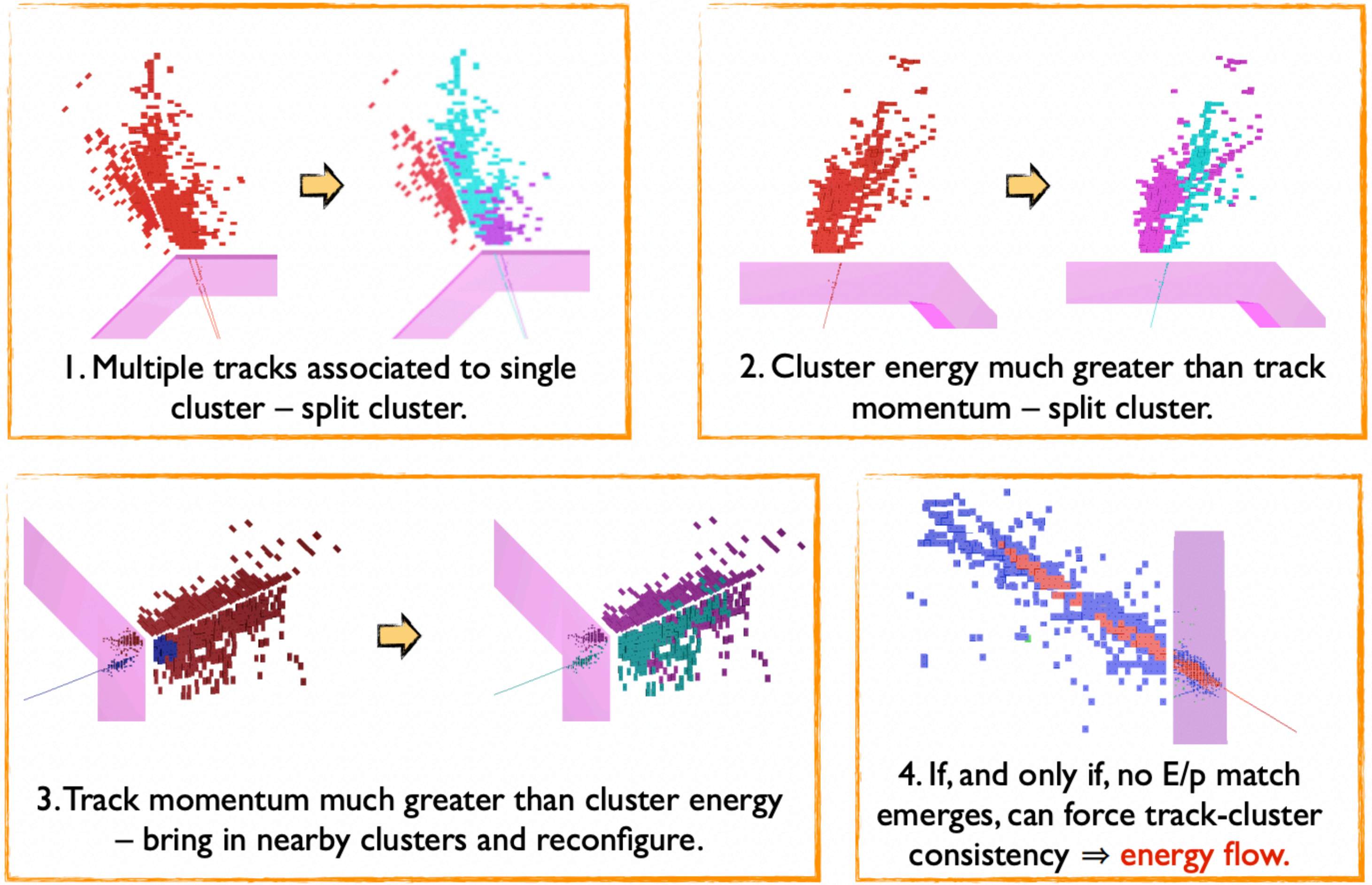


Geometry Adaptations to CLD

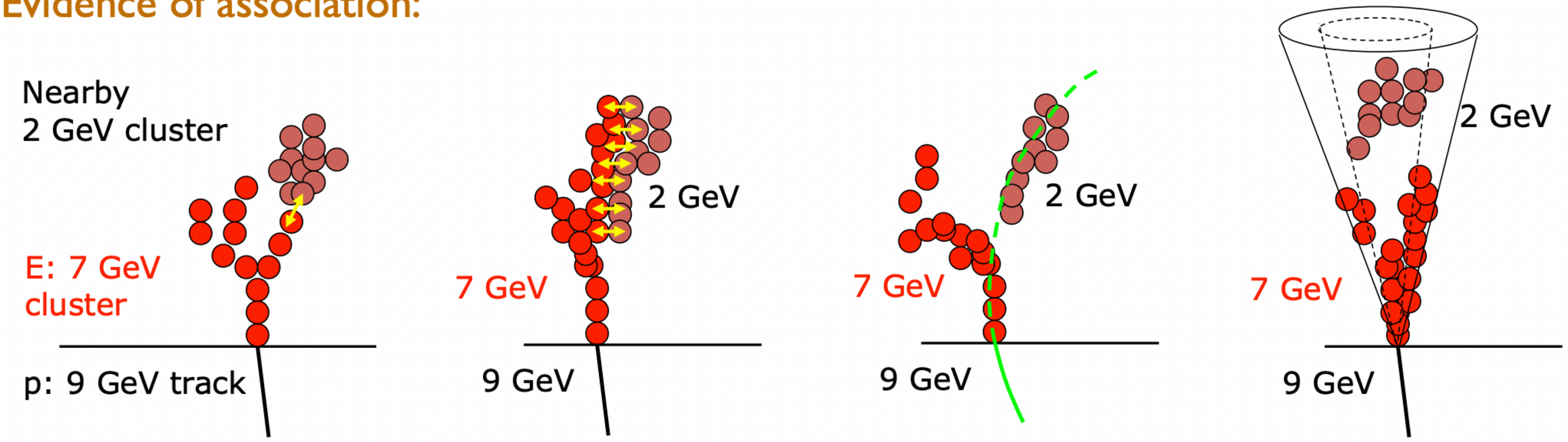
- Challenge - no full simulation for ALLEGRO in Key4hep yet
- Need tracks for Pandora PFA
- Using CLD detector as a base for full simulation and reconstruction a detector model as **`CLD_o4_v05`** was created with LAr calorimeter as the ECAL
- The LAr ECal is almost three times the size of the CLD ECAL
- 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



Evidence of association:



Small distance of closest approach

Multiple layers in close contact

Small distance to track extrapolation

Large fraction of energy in cone