Status of the FCC-ee LAr calorimeter software

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FCC Noble Liquid Calorimetry group

FCC Physics Workshop
Feb. 11th, 2022

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Outline

- Detector description
- Calorimeter reconstruction
- Performance studies
- Missing ingredients

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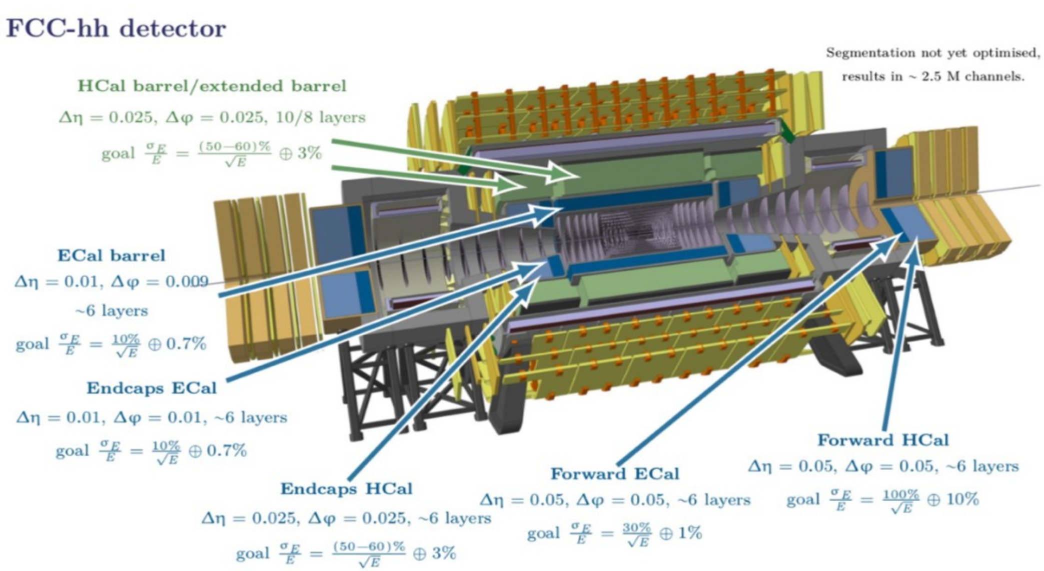
- Calorimeter reconstruction
- Performance studies
- Missing ingredients

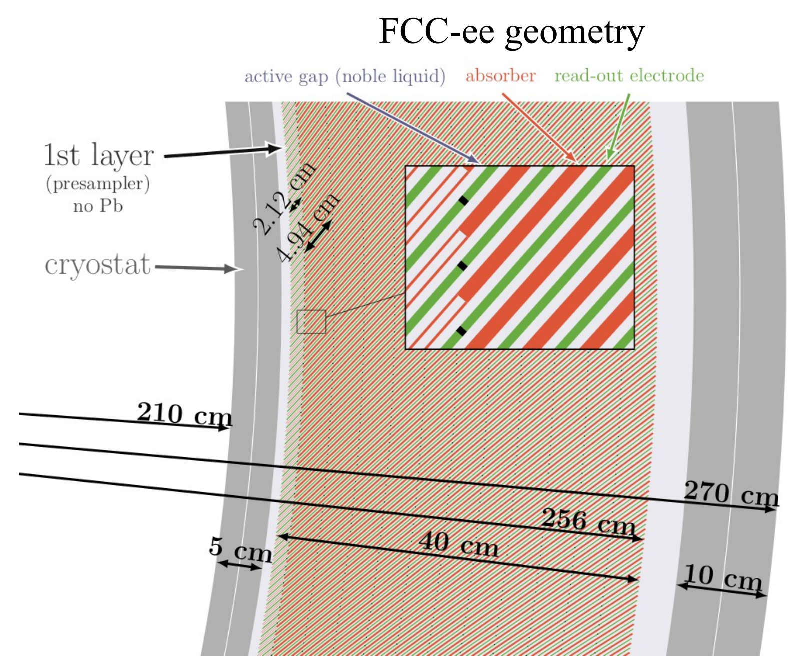
Not an exhaustive description of the technical aspects, trying instead to bridge physics needs with available software to help people that would like to start (LAr) Calo studies!

Will only talk about Full Sim

Introduction

- Sampling calorimeter: Liquid Argon (LAr) or Krypton (LKr) as sensitive media, Lead (Pb) or Tungsten (W) as absorber with multi-layer PCB readout electrodes, everything inside a cryostat (Aluminum or Carbon Fibre)
  - Straight plates inclined by 50^{o} (signal extraction and azimuthal uniformity)
- Baseline for FCC-hh (radiation hardness, …)
- Very interesting option for FCC-ee (high control over systematics, resolution, …)
  - R&D ongoing for high longitudinal segmentation (Particle Flow)
  - More details about this detector in this talk



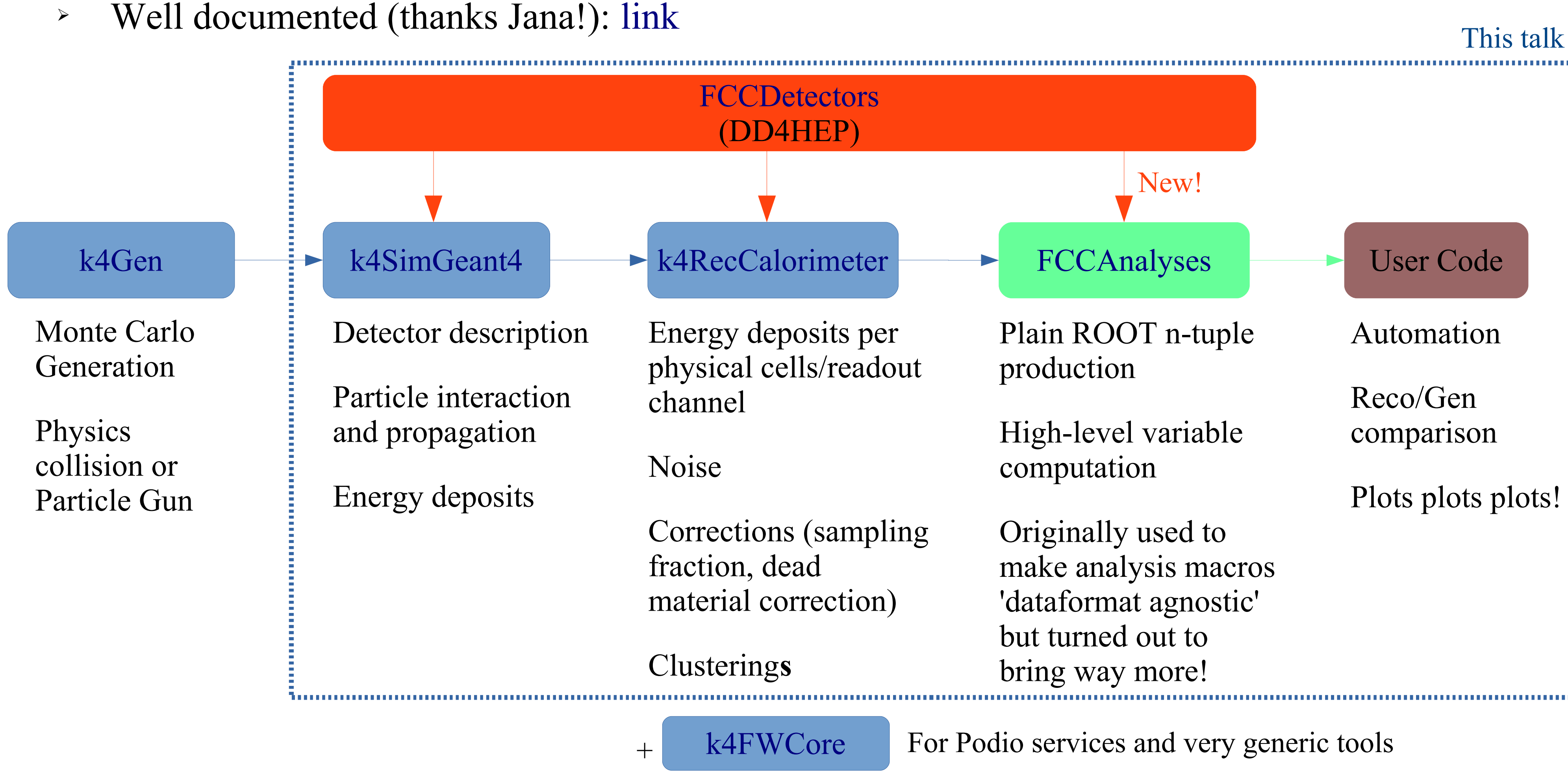


LAr Calo Full Sim in a nutshell

- LAr Calorimeter Full Sim chain in a nutshell (schematic)
  - FCC-hh CDR Calorimeter studies based on FCCSW with fcc::edm
  - **Everything migrated to EDM4HEP** (Podio based) and **integrated to the Key4HEP** stack last year (thanks Valentin)!
  - Well documented (thanks Jana!): link

Legend: Gaudi based

Links to code

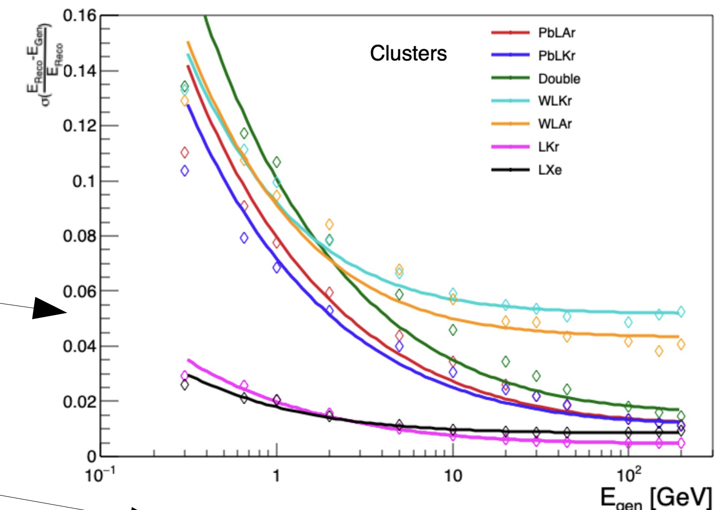


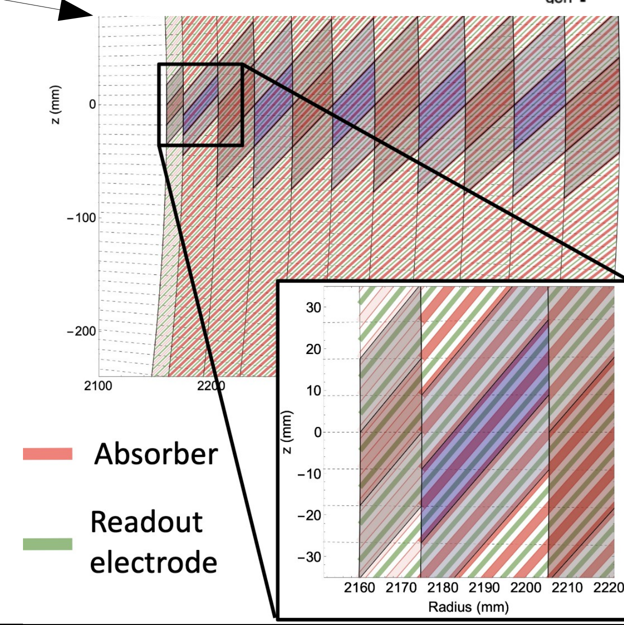
Detector description

Detector description (I)

- **Factorized** Detector Building (DD4HEP)
  - C++ detector factory: handles the **generic geometry structure**
    - Cryostat cylinder, inclined plates, …
  - XML file with **specific detector parameters**
    - Inner/Outer radius, materials, inclination, …
  - Allows you to study different scenarios with minimal work
- Detector segmentation based on DD4HEP Readouts
- Readout cells differ in general from physical cells
  - E.g. having high sampling frequency improves energy resolution → phi granularity higher than what physics requires
  - Flexibility choice: do the time consuming Geant4 simulation with atomic granularity, then apply (possibly several) cell recombinations with RedoSegmentation
- Caveats
  - The same cell recombination scheme is applied to the whole calorimeter
    - One would like to have smaller cells for e.g. the strip layer
  - The cell position assignment would benefit from a refactoring

FCCDetectors (DD4HEP) | k4SimGeant4





Detector description (II)

FCCDetectors (DD4HEP)

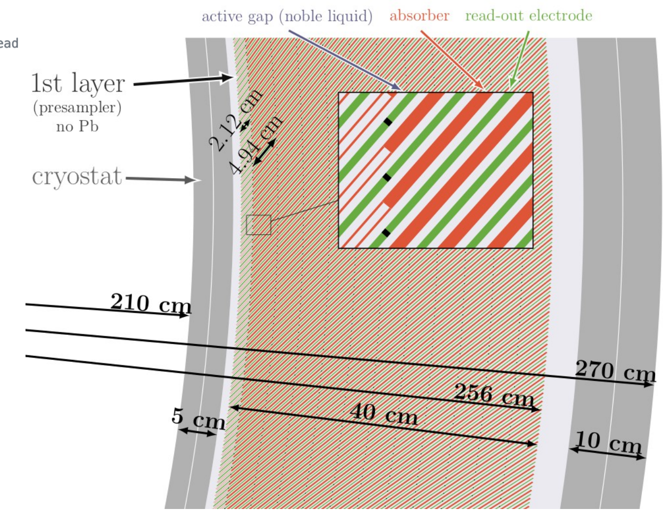
k4SimGeant4

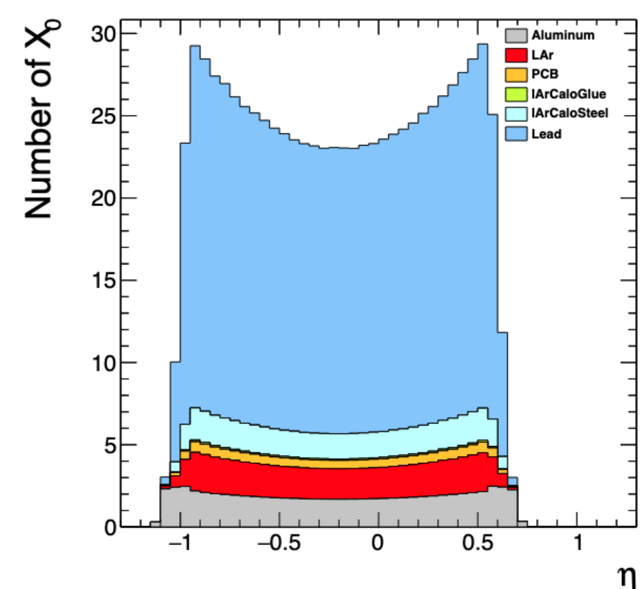
- Accurate FCC-ee detector description
  - 1536 absorber plates: 100 µm Steel sheet + 100 µm glue + 1.8 mm Lead
  - 2 x 1.2 mm sensitive LAr gap (widening towards high radius) + 1.2 mm PCB
  - Typical readout cells size
    - $\theta \times \Phi \times r \sim 2$ (0.5 strip) $\times 1.8 \times 3$ cm^3
  - Aluminum cryostat + space reserved for services (filled with LAr)
  - 40 cm depth sensitive area, ~23 X_0 including the cryostat
- So far, **only the** **Barrel ECAL** has been implemented for the FCC-ee geometry
  - Currently working on Endcap LAr ECAL implementation

materials.xml

```xml
<!-- prepreg glue (C5H8O4Si) between steel and lead
<!-- from ATL-LARG-PUB-2009-001 -->
<material name="lArCaloGlue">
  <D value="1.69" unit="g/cm3" />
  <composite n="5" ref="C"/>
  <composite n="8" ref="H" />
  <composite n="4" ref="O" />
  <composite n="1" ref="Si" />
</material>

<!-- stainless steel as in ATLAS EM calo -->
<!-- from ATL-LARG-PUB-2009-001 -->
<material name="lArCaloSteel">
  <D value="7.84" unit="g/cm3" />
  <fraction n="0.7175" ref="Fe"/>
  <fraction n="0.19"   ref="Cr" />
  <fraction n="0.0925" ref="Ni" />
</material>
```

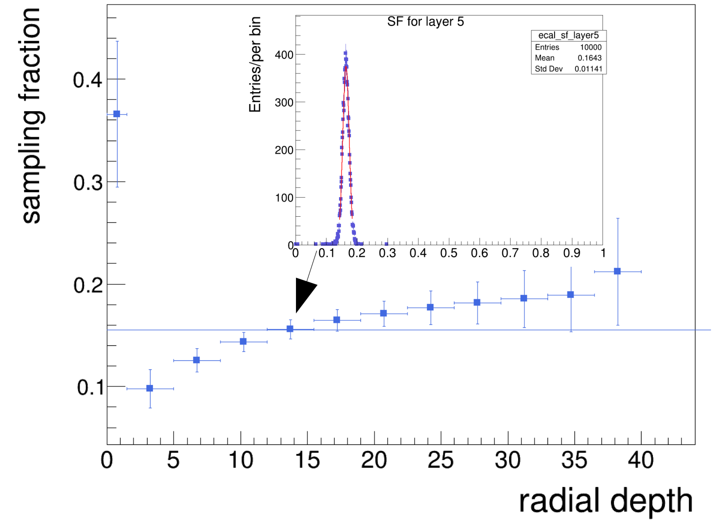


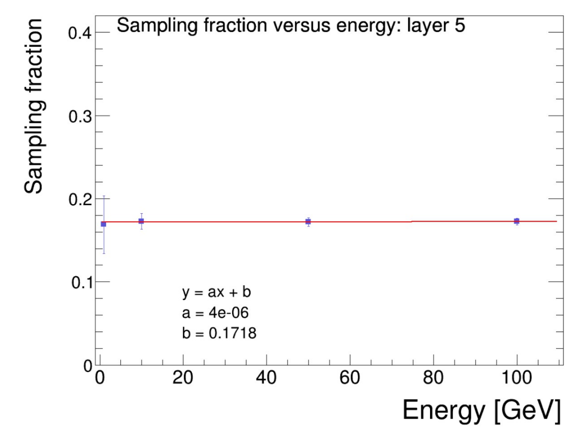


Reconstruction

Sampling Fraction

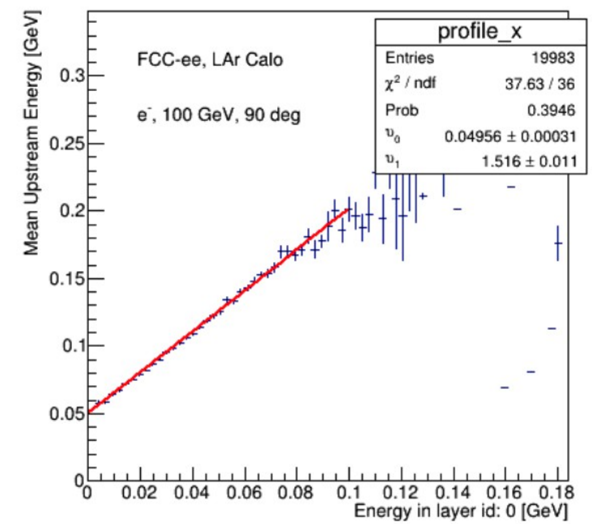
- In a Sampling Calorimeter, only a fraction of the particle energy is measured
  - One scales each cell energy to account for energy deposited in absorber and PCB
- Modified detector config with the absorbers set as sensitive (XML)
  - SamplingFractionInLayers stores the energy ratio (active/passive) per event and per longitudinal layer [k4SimGeant4]
  - [User Code] SF = mean of Gaussian fit of the active/passive energy ratio
  - Propagate results to CalibrateInLayersTool [k4RecCalorimeter]
  - Fully automatized procedure (with control plots)
    - Everything defined in a Gaudi config can be passed as command line argument
    - Or you can use sed for more permanent usage
- In a Noble Liquid calorimeter, the sampling fraction has almost **no dependence on the incident particle energy**
  - No need to apply this procedure to many energy points

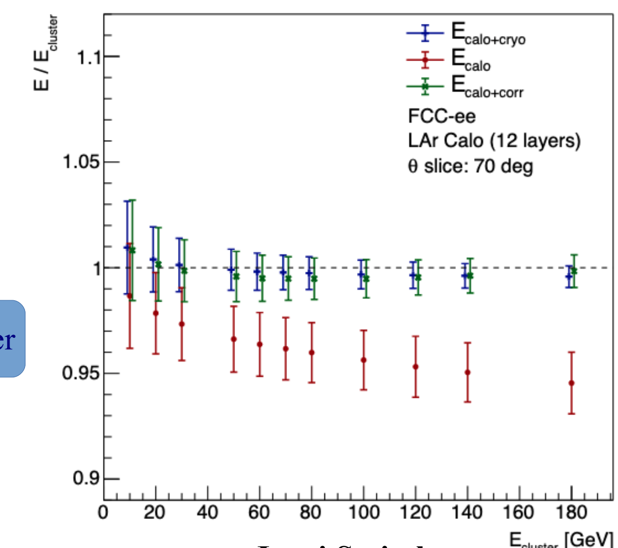




Upstream/Downstream energy correction

- Unmeasured **energy deposited in upstream material**: calorimeter supporting structure/cryostat, magnet, services, …
- Always try to minimize calorimeter radial extent + stochastic nature of shower depth → **energy deposited after the calorimeter**
- **Strong correlation** between energy in first(last) sensitive layer and energy deposited upstream(downstream) → **one can correct for that!**
  - EnergyInCaloLayers → stores energy in various dead materials and in all the active layers (modified XML) k4SimGeant4
  - Centrally available scripts perform the fits
  - CorrectCaloClusters → applies the correction based on cluster total energy and energy from first/last layer k4RecCalorimeter
- Again, fully automatized procedure with intermediate diagnostic plot production

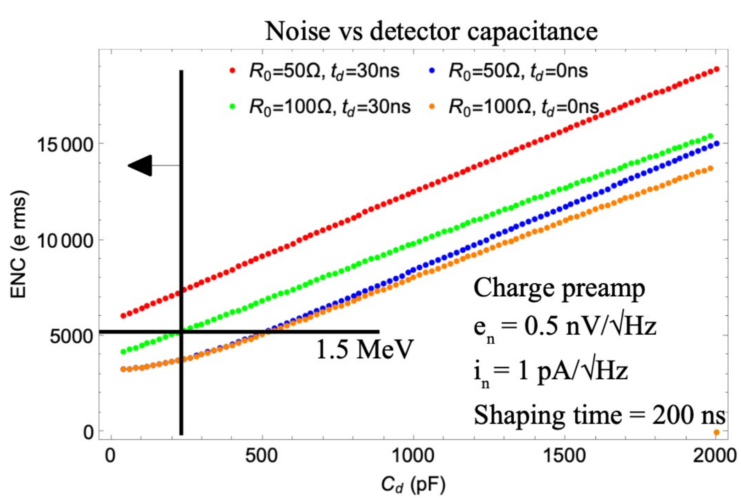


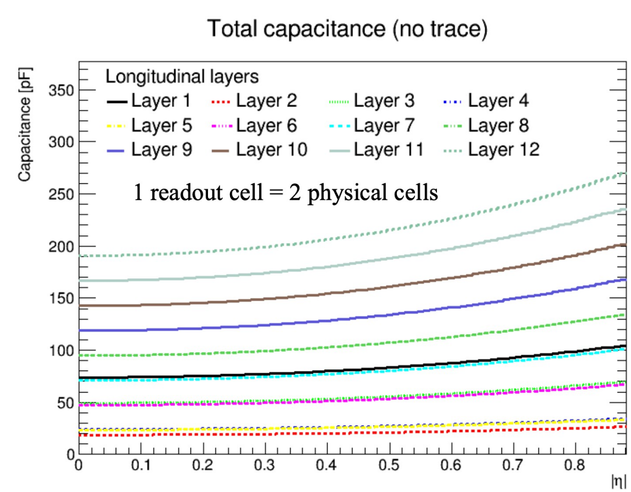


Juraj Smiesko

Noise

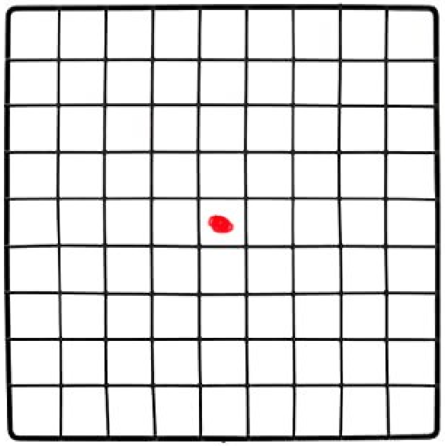
- Noise depends on many factors
  - Detector capacitance, signal extraction scheme, front-end electronics, etc...
  - **Estimated outside of the main software** framework: Finite Element Method tools (Ansys) + analytical implementation (Mathematica)
  - Stored in a rootfile, per longitudinal layer and as a function of polar angle
- Introduced in the simulation by NoiseCaloCellsFromFileTool k4RecCalorimeter
  - Random number from Gaussian whose width is taken from the rootfile (layer/Θ dependent)
  - Added only after the final readout segmentation step (cell geometry dependance)
- Very tricky to fully automatize 😐

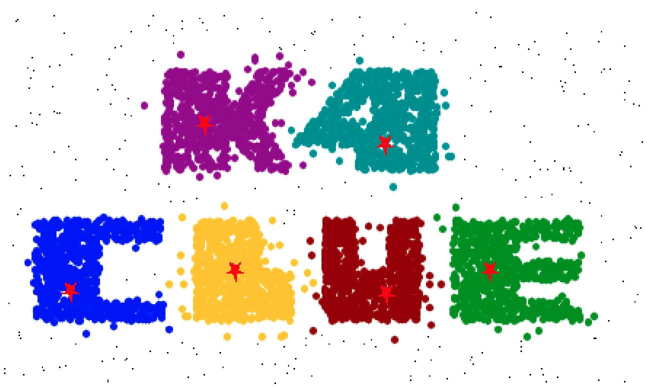


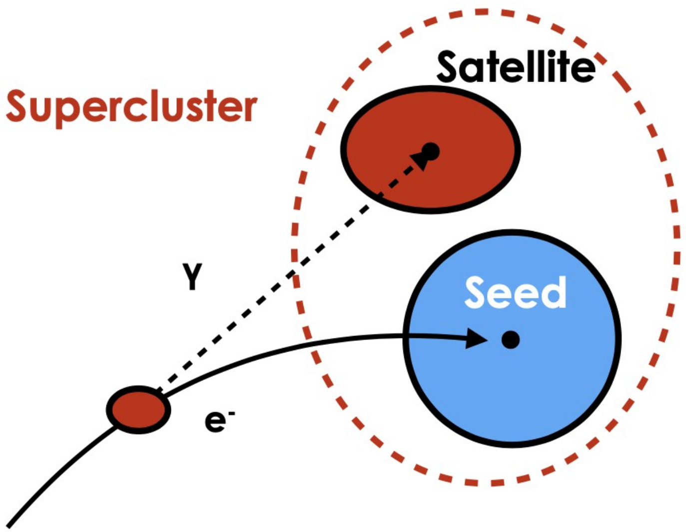


Clustering

- Two clustering algorithms available — k4RecCalorimeter
  - CreateCaloClustersSlidingWindow
    - Simple sliding window with fixed size
  - CaloTopoCluster
    - Find seeds and iteratively collects cells in several steps of S/N thresholds
- Will soon try out the standalone CLUE algorithm







Performance studies

Practical workflow example

- Little user specific code needed to orchestrate these tools and automatize the sequence

LXPlus HTCondor submission script

- Less events per job towards higher energy → 10 energy points (1 – 200 GeV) with 10 k events takes < 2 hours
- Writes all the subsequent shell scripts

k4Gen | k4SimGeant4 | k4RecCalorimeter

RunCaloSim.py

Shell script →

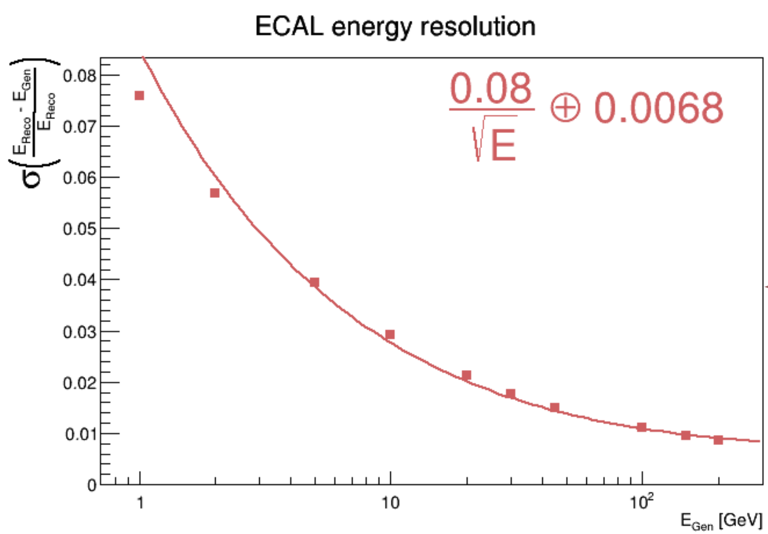
FCCAnalyses CaloNtupleizer

- Outputs plain ROOT n-tuples
- Very easy to analyze with simple macros
- Parametrizable object content
- Can store multiple objects of the same type (e.g. Sliding Window and Topo Clusters)
- Can access DD4HEP geometry information (decode the cellID)

Shell script ↓

Simple analysis macro

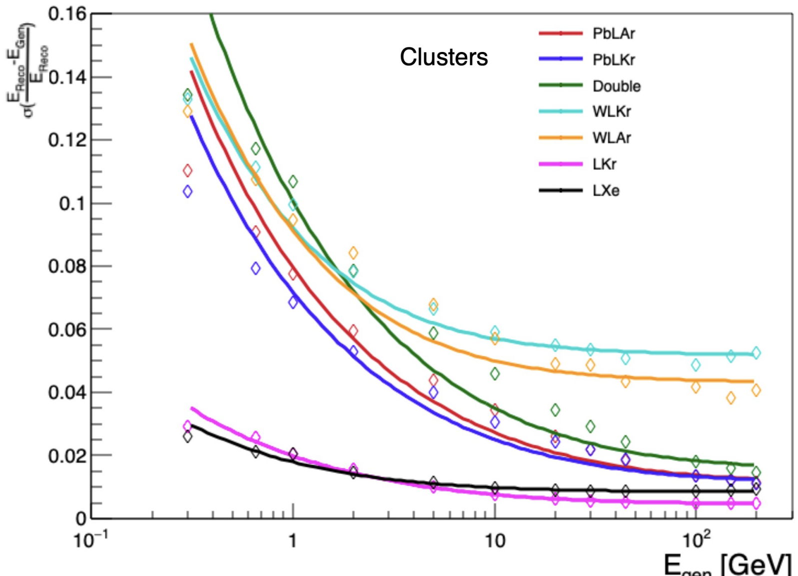
Outputs ←



Performance results

- Example of performance results produced recently with FCC-ee LAr ECAL

Energy resolution for different absorber and Noble Liquid material

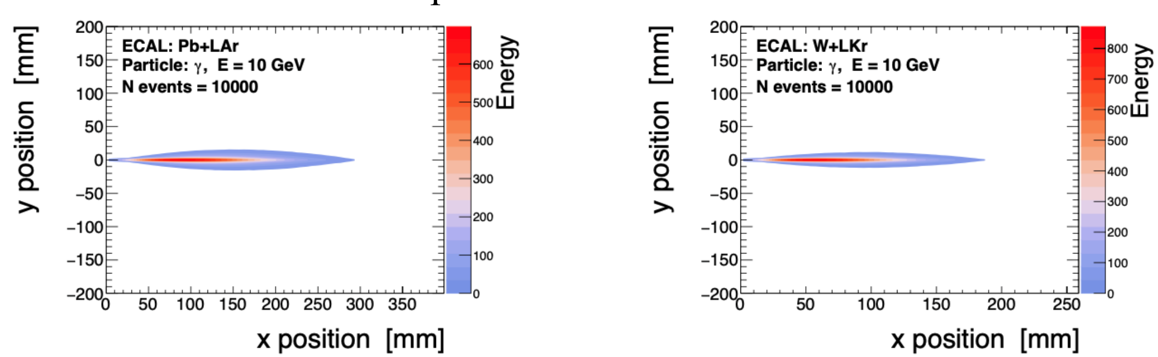


Mark Waterlaat

τ final state categorization confusion matrix

Recon → Gen ↓	$\pi^\pm \nu$	$\pi^\pm \pi^0 \nu$	$\pi^\pm 2\pi^0 \nu$	$\pi^\pm 3\pi^0 \nu$	$\pi^\pm 4\pi^0 \nu$
$\pi^\pm \nu$	**0.9560**	0.0425	0.0010	0.0003	0.0002
$\pi^\pm \pi^0 \nu$	0.0374	**0.9020**	0.0586	0.0016	0.0002
$\pi^\pm 2\pi^0 \nu$	0.0090	0.1277	**0.7802**	0.0808	0.0022
$\pi^\pm 3\pi^0 \nu$	0.0036	0.0372	0.2679	**0.5972**	0.0910

Moliere Radius comparison between Pb + LAr and W + LKr



$R_M = 41$ mm

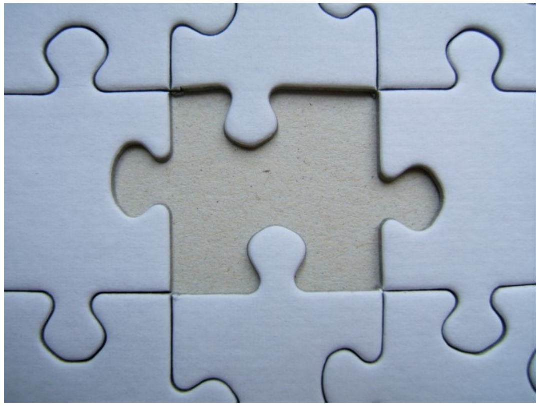
$R_M = 27$ mm

Katinka Wandall-Christensen and Mogens Dam

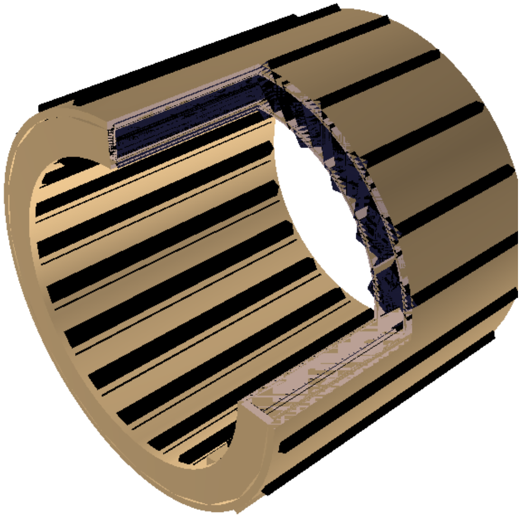
- Stay tuned, more to come!
  - Not so far from being able to do a first Full Sim physics analysis (e.g. Axion → γγ once we have the ECAL endcap)

What do we need more?

- Wishlist
  - **Particle Flow!** (or simply track to calo cluster association)
    - **A comprehensive detector optimization (especially for the granularity) can not be done without this**
  - A stable and 'high resolution' **visualization tool**
    - Helps a lot for detector geometry validation
      - Need to check tiny features (e.g. LAr gap widening, segmentation)
  - Physics objects reconstruction



- Missing ingredients for further detailed calorimeter studies
  - Cross-talk emulation
  - Detector non uniformities (can this be done easily in DD4HEP?)
  - Proper digitization
  - Central algorithm deriving cluster axis and shape variable
  - Many algorithms still rely on η detector segmentation and should be moved to a Θ segmentation (FCCSWGridPhiTheta already available)



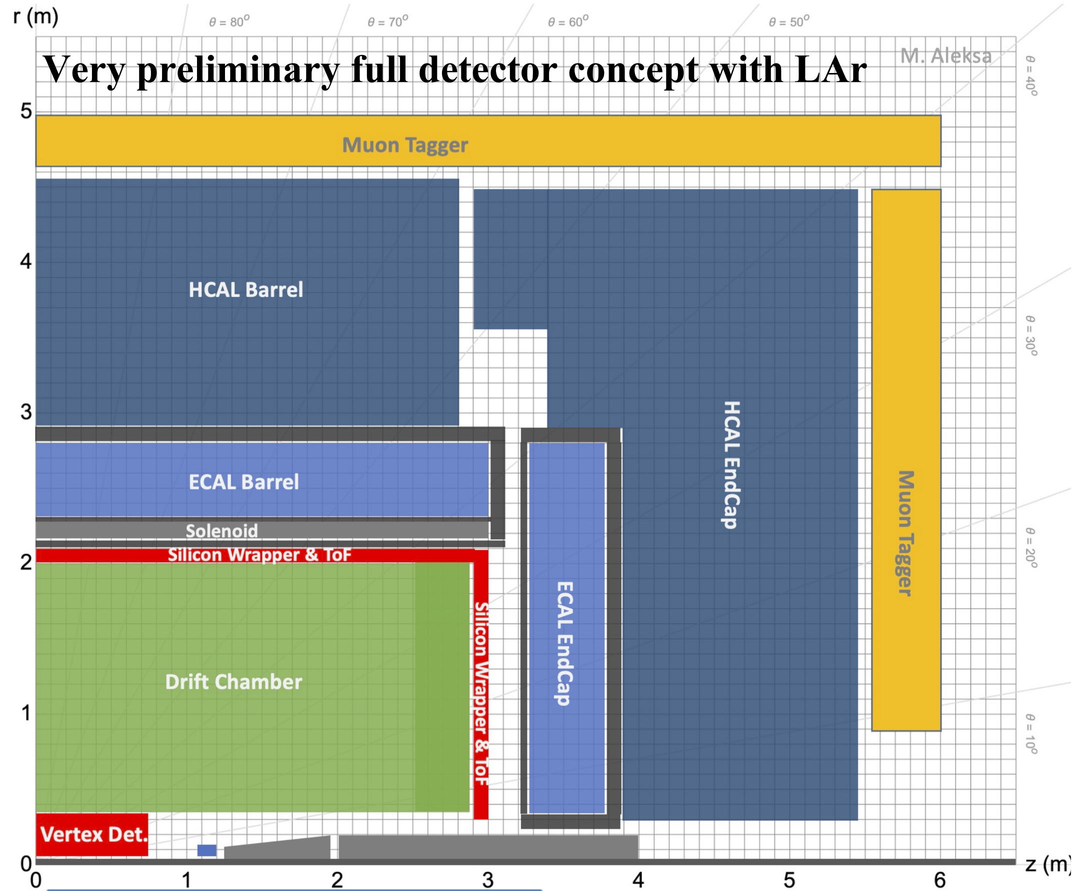
Jana Faltova (GeoDisplay)

Towards a full detector concept

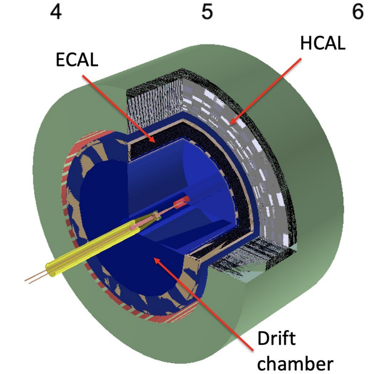
- So far, we simply replaced the calorimeter from the IDEA detector by the LAr one
  - **DetFCCeeIDEA-LAr**
  - 'Plug-and-Play' thanks to the framework flexibility

```
<include ref="../../DetFCCeeIDEA/compact/Beampipe.xml"/>
<include ref="../../DetFCCeeIDEA/compact/BeamInstrumentation.xml"/>
<include ref="../../DetFCCeeIDEA/compact/LumiCal.xml"/>
<include ref="../../DetFCCeeIDEA/compact/HOMAbsorber.xml"/>
<include ref="../../DetFCCeeIDEA/compact/Vertex.xml"/>
<include ref="../../DetFCCeeIDEA/compact/DriftChamber.xml"/>
<include ref="../../DetFCCeeECalInclined/compact/FCCee_ECalBarrel.xml" />
<include ref="../../DetFCCeeHCalTile/compact/FCCee_HCalBarrel_TileCal.xml" />
```

- We are now thinking at a **full detector concept to** be implemented in FCCSW
  - Exciting exercise that requires a lot of diverse expertise
  - Please join!



Detector Concept
- Vertex Detector:
  - MAPS or DMAPS possibly with timing layer (LGAD)
- Drift Chamber (±2.5m active?) – TPC?
- Silicon Wrapper + ToF:
  - MAPS or DMAPS possibly with timing layer (LGAD)
- Solenoid B=2T, sharing cryostat with ECAL
- High Granularity ECAL:
  - Noble liquid + Pb or W
- High Granularity HCAL / Iron Yoke:
  - Scintillator + Iron
    - SiPMs directly on Scintillator or
    - TileCal: WS fibres, SiPMs outside
- Muon Tagger:
  - Drift chambers, RPC, MicroMegas

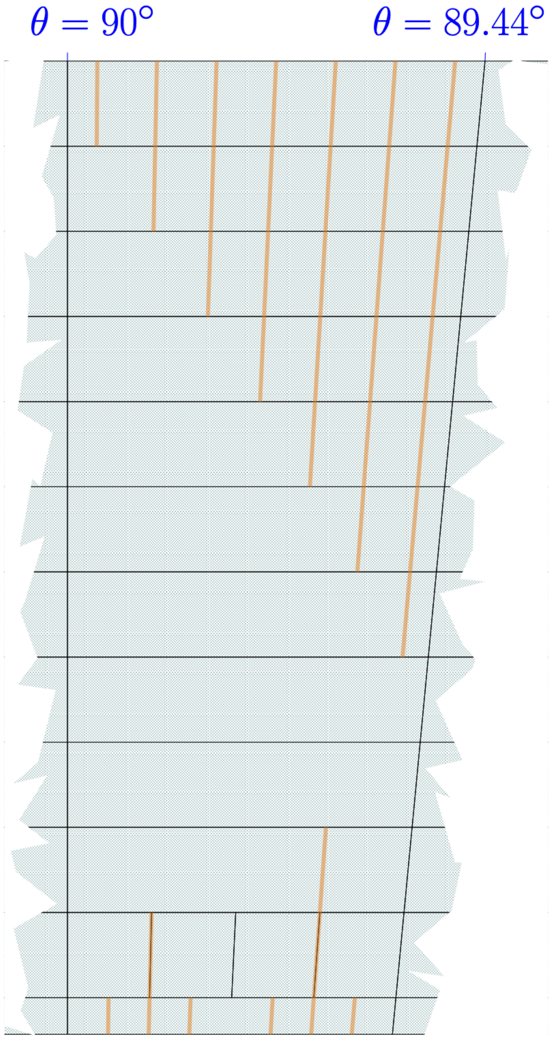


Summary

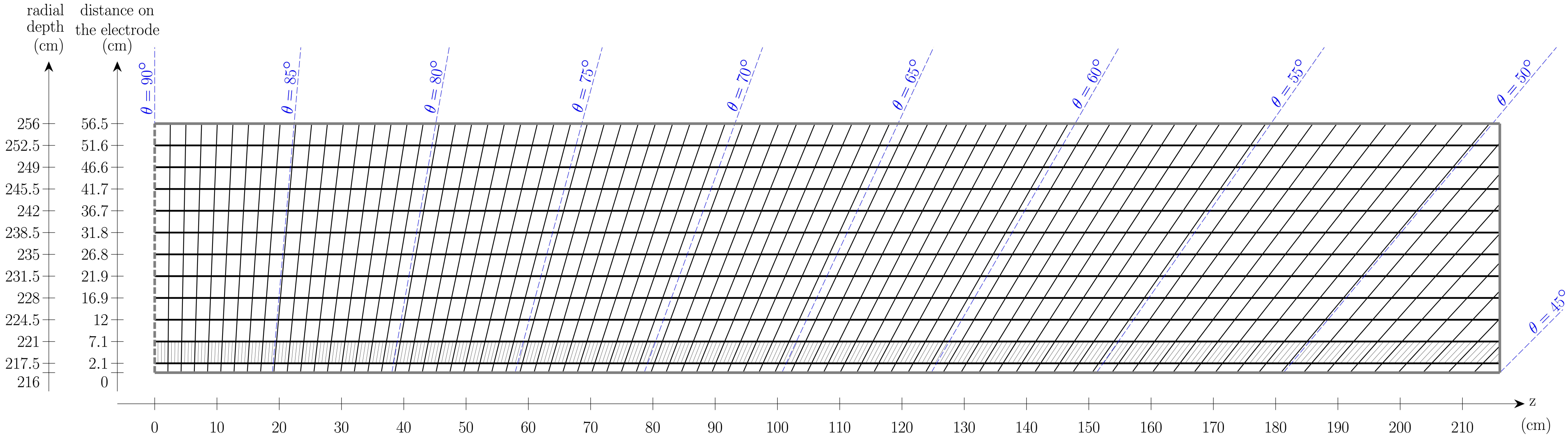
- The FCC-ee LAr Calo software has been fully ported to EDM4HEP and integrated in Key4HEP
- Accurate and flexible description of the geometry and materials (DD4HEP)
- All the tools for reliable first order **Full Sim performance studies are available**
  - Sampling fraction, dead material correction, noise, …
- **Missing** ingredients
  - **Particle Flow!**
    - No comprehensive detector optimization is possible without this
    - A minimalist Track to CaloCluster association would already be very helpful!
  - Second order effects for even more accurate performance studies
    - Digitization, X-talk, detector non-uniformities, …
- See also: Valentin's talk for a tutorial like guide through the Full Sim!

Additional material

Readout electrodes



Readout electrodes



Upstream energy correction

FCC-ee, e^-, 100 GeV, $\theta = 70°$