FCC-ee Detector Full Simulation Implementation

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Oct. 11th, 2023

FCC-ee Detector Full Simulation Implementation

- Software ecosystem
- Status of detector implementation
- Detector studies
  - Status of full simulation
  - Status of reconstruction and Analysis
- Summary

Software ecosystem

- Key4hep software stack, see J. Carceller talk tomorrow

Software ecosystem

- Key4hep software stack
- Data format is EDM4hep
- Detector Geometry built by DD4hep
  - Central repository for geometry: k4geo
  - The geometry is **always** fed to the simulation as a **DD4hep** detector description
  - CAD designs are translated by DD4hep before running the simulation

Event data
Detector Geometry

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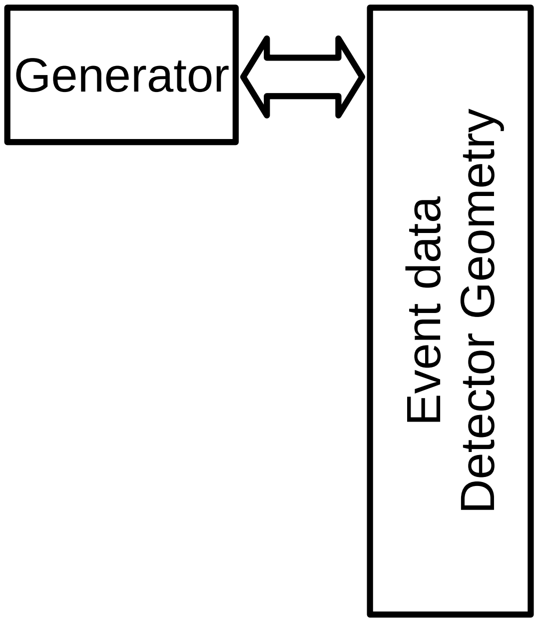

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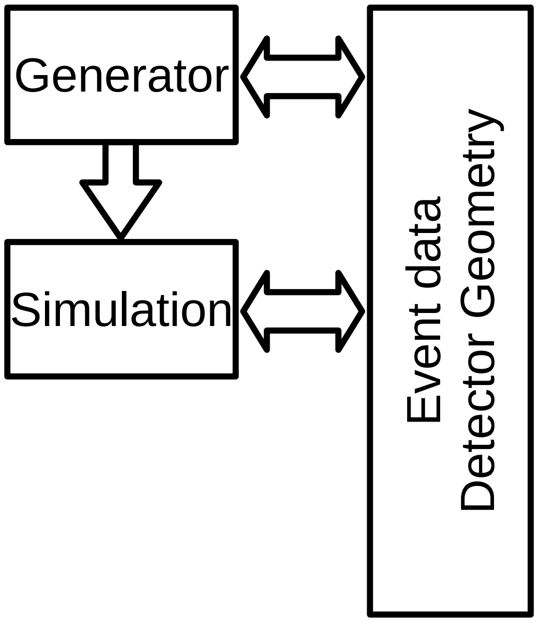

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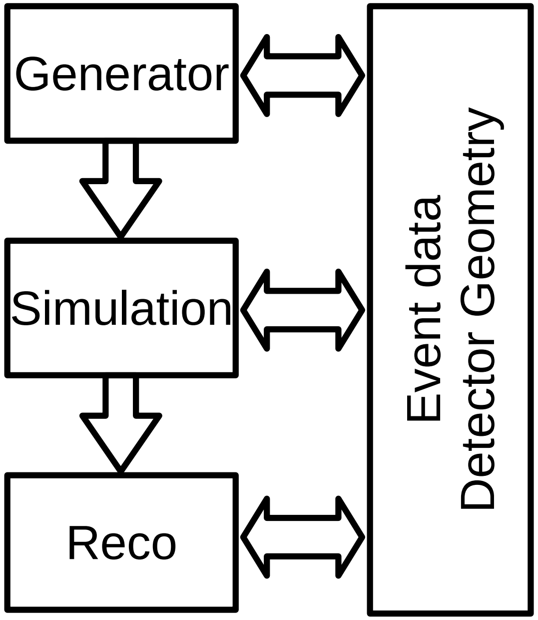
  - Several repositories for reconstruction



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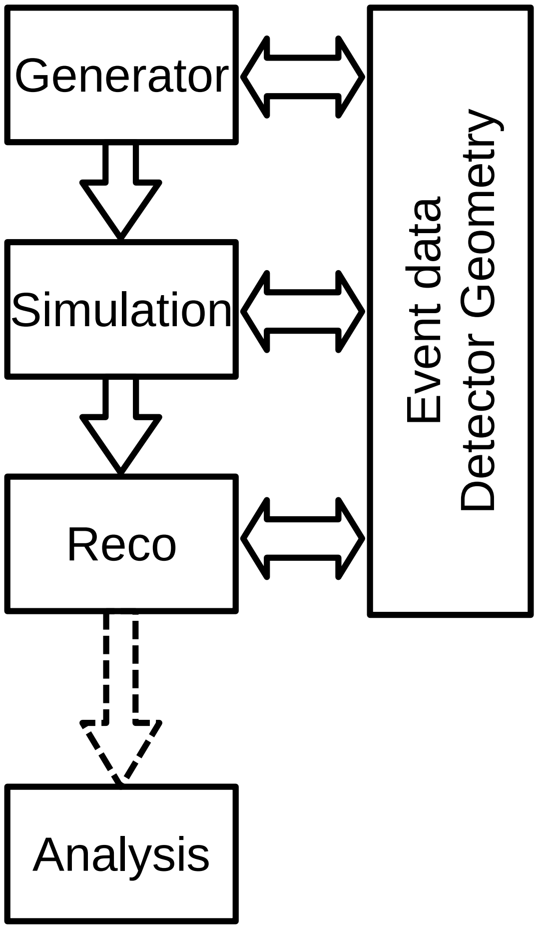
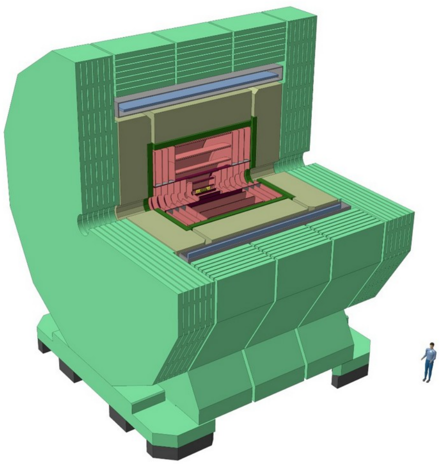
- Dedicated framework for analysis

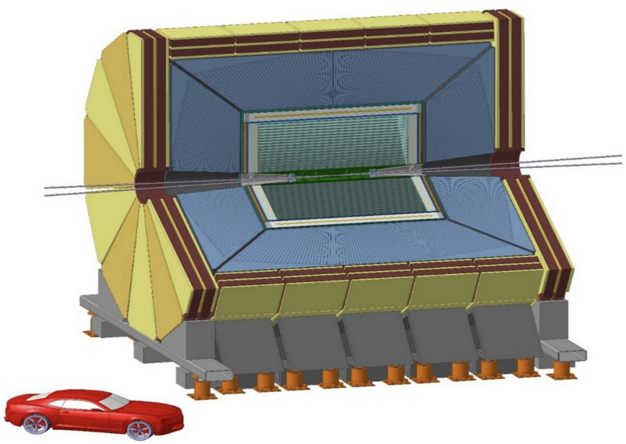


Status of detector implementation

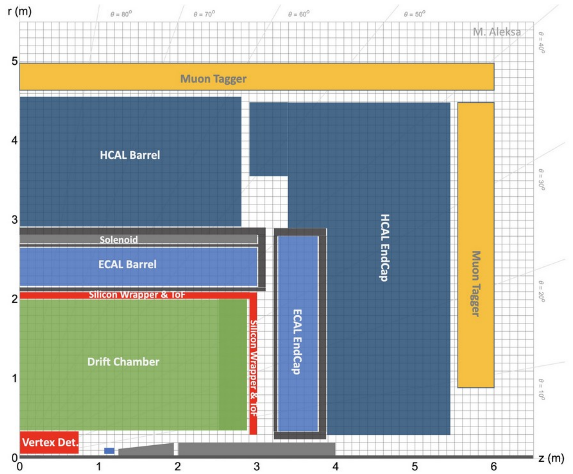
- Three main detector concepts:



CLD



IDEA



ALLEGRO

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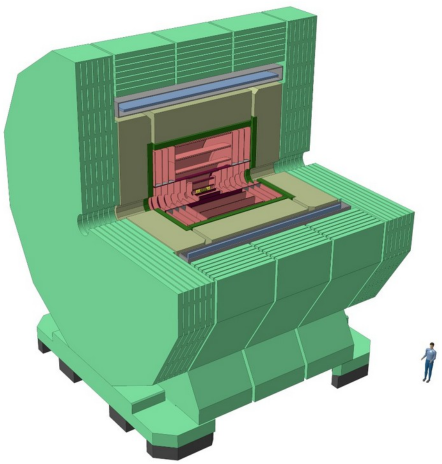

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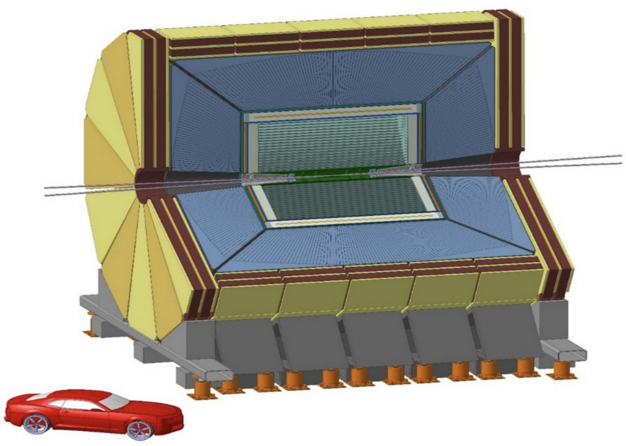

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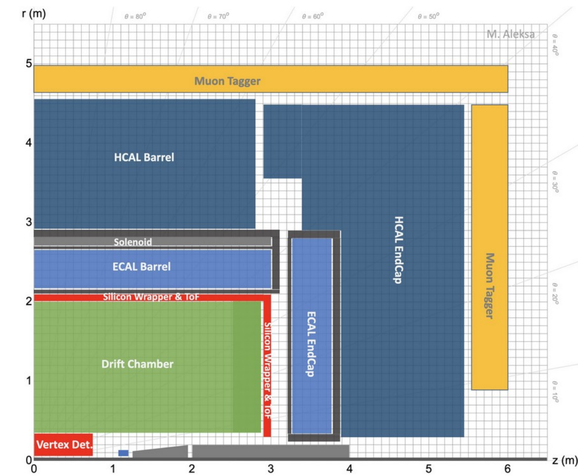

ALLEGRO

- Subdetectors can be interchanged, e. g.
  - IDEA and ALLEGRO share inner subdetectors
  - Beam pipe is common to all

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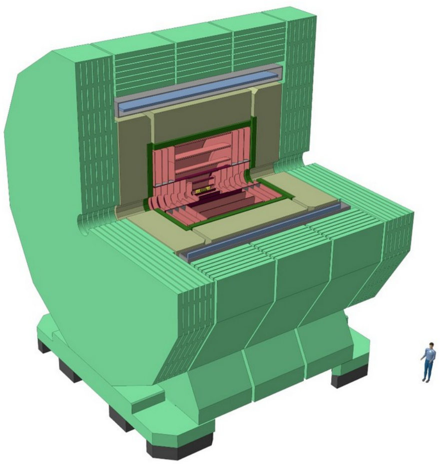

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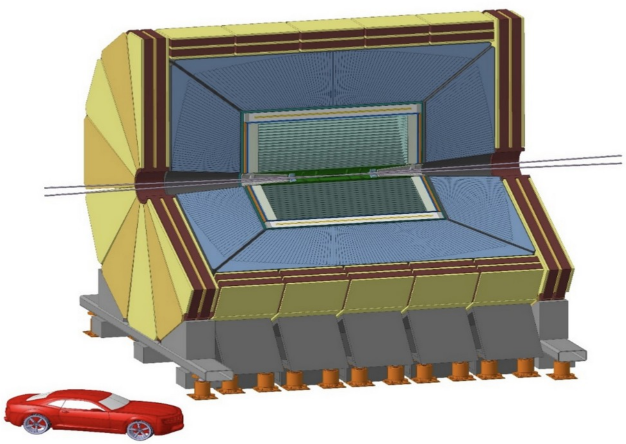


IDEA

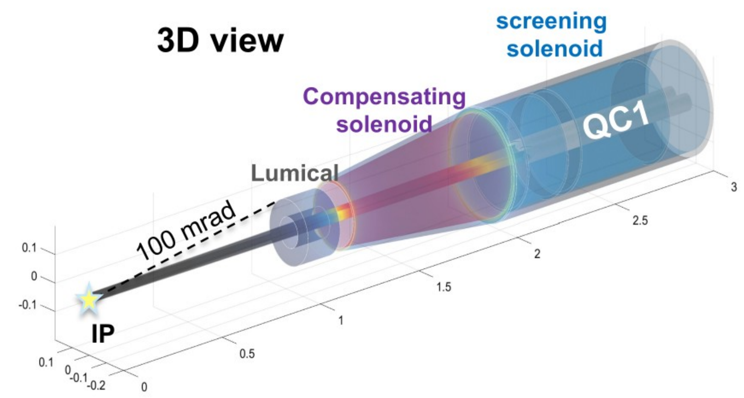
ALLEGRO

- Subdetectors can be interchanged, e. g.
  - IDEA and ALLEGRO share inner subdetectors
  - Beam pipe is common to all
- **Many people** behind each subdetector

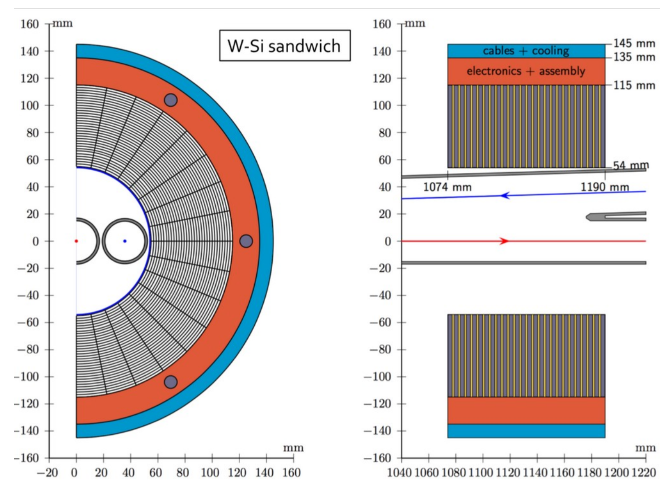
Beam pipe

A. Ciarma

- Beam pipe is common to all detectors
  - DD4hep implementation based on CAD design [link]
  - Study of shielding efficiency is ongoing

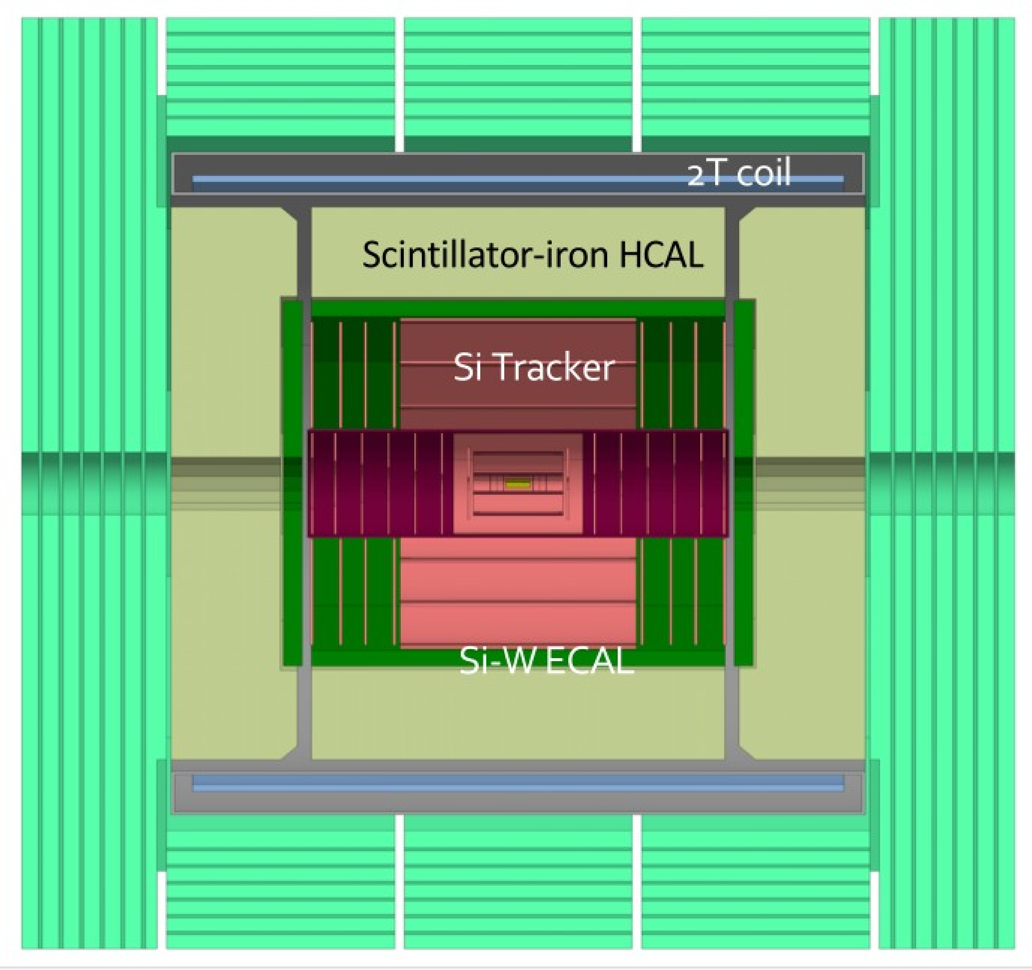


- Lumical is a W-Si detector coming from ILD
  - Upgrades are ongoing (J. Jallberg, M. Dam)
- See M. Boscolo talk for further details about the mechanical design



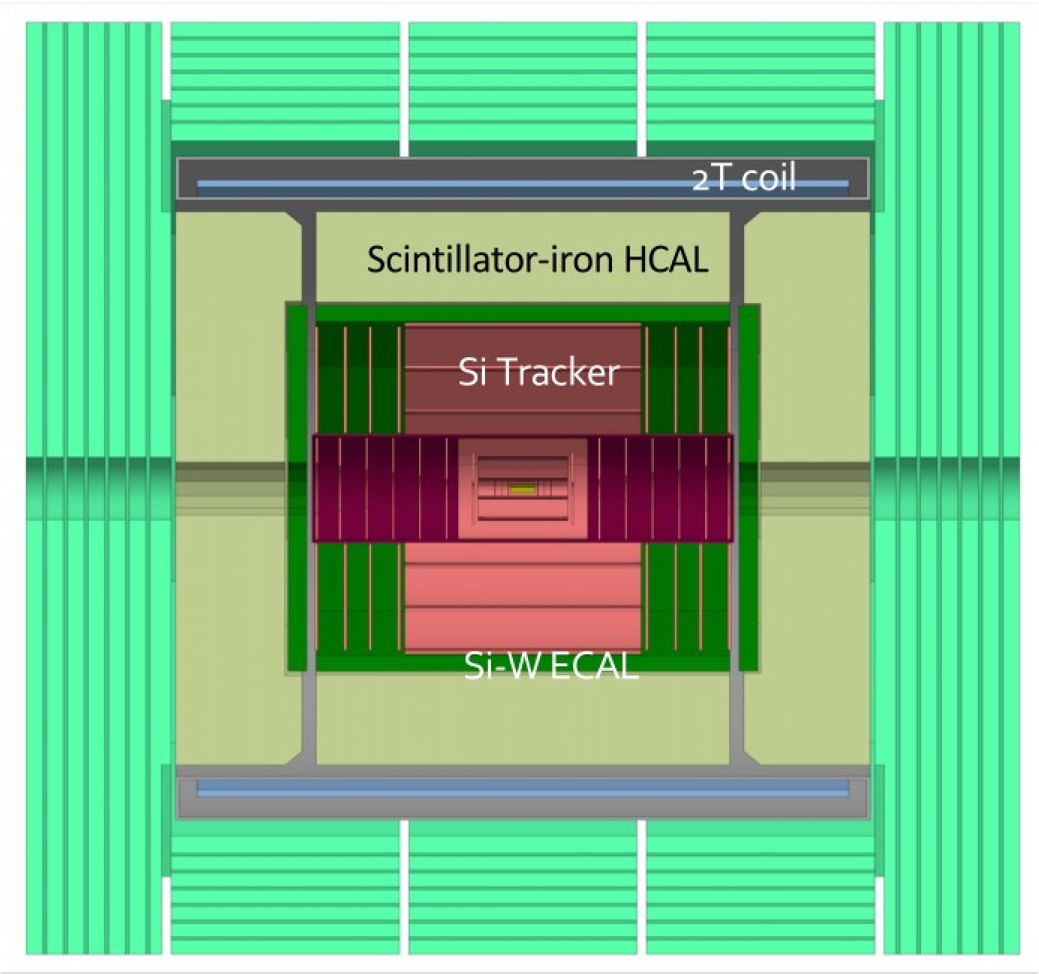
CLIC Like Detector, CLD

- Full simulation and reconstructions is available



CLIC Like Detector, CLD

- Full simulation and reconstructions is available
- The main components are:
  - Silicon-based Vertex and Tracker
  - Highly granular calorimeters
  - Coil, surrounds calorimeter systems



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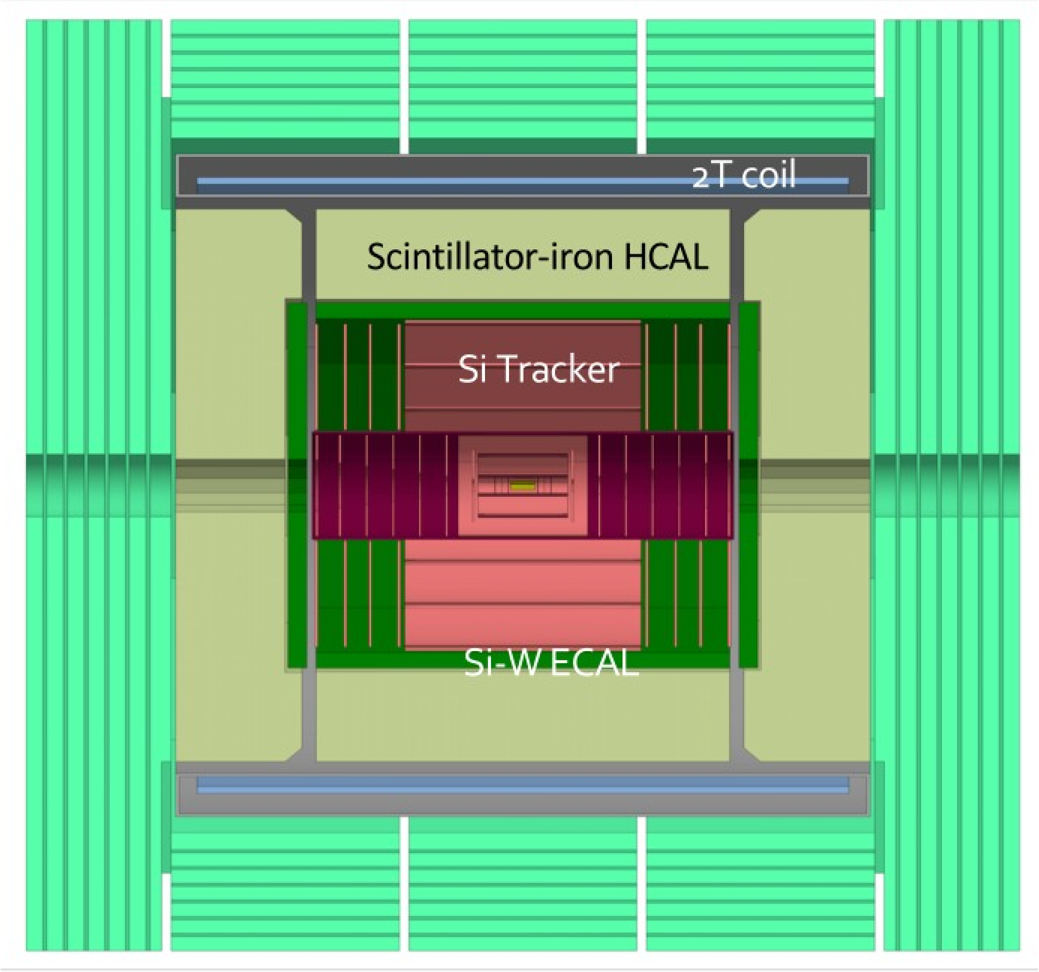
- More details in A. Sailer presentation tomorrow



CLD evolution

- There are plans to use CLD as a test bed for full simulation studies
    - Various tracking algorithms and layout studies (see L. Reichenbach presentation)
    - Optimization of the tracker geometry driven by the impact on tracking and vertexing resolution and flavor tagging (G. Sadowski, Z. El Bitar, J. Andrea)

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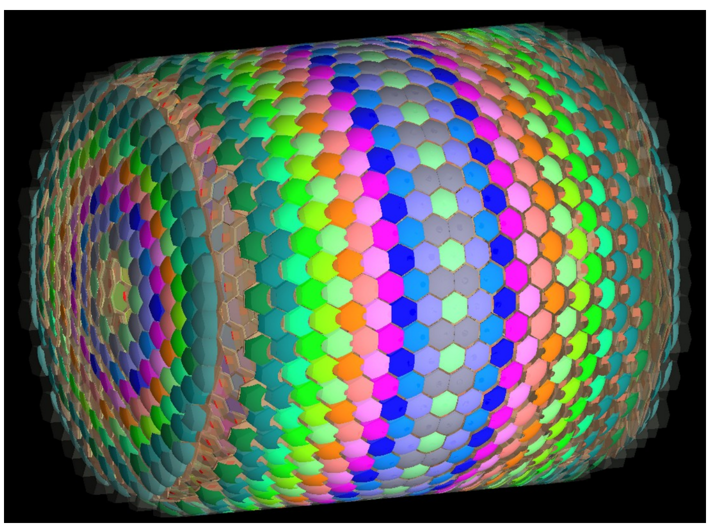
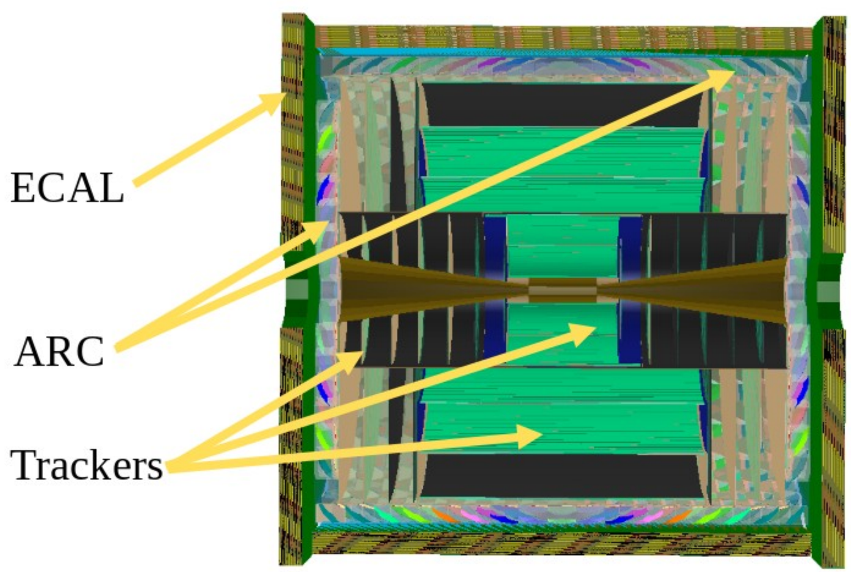
- Version of CLD with ALLEGRO ECAL, see S. Sasikumar presentation
  - Current aim is to study particle flow based on Marlin Pandora PFA
  - Pandora requires information about the material properties of the calorimeter, e.g., radiation length, interaction length, and dimension of the reconstruction algorithm
  - The end goal is to develop a native version of Pandora in key4hep

CLD option with ARC

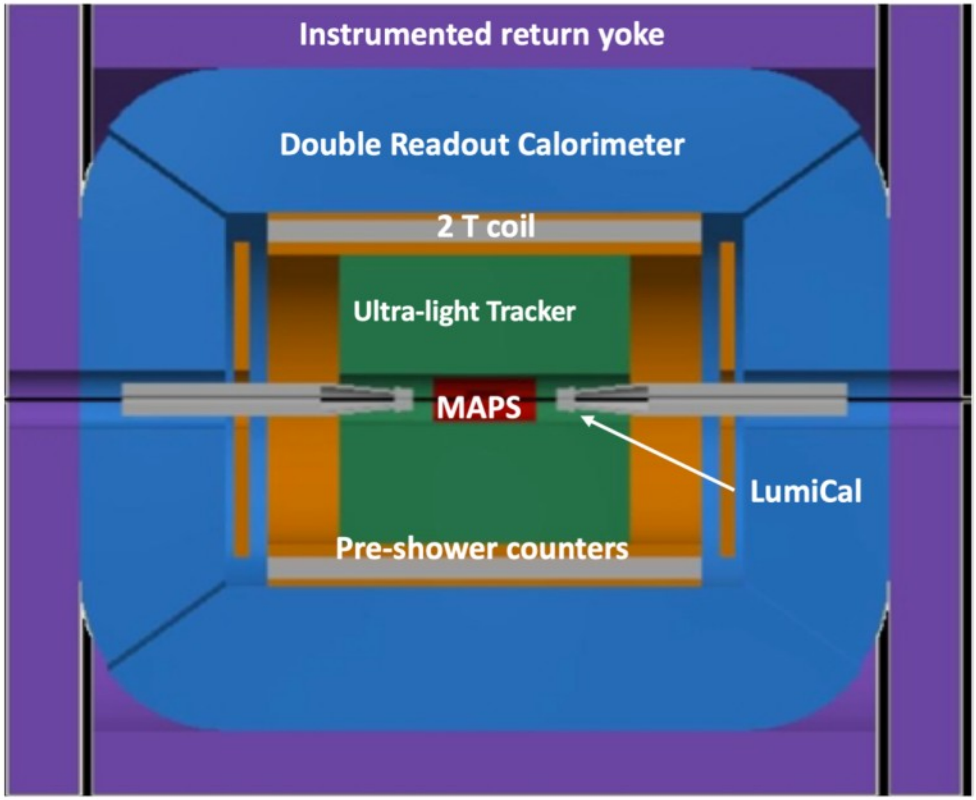
- New option of CLD to accommodate ARC subdetector (A. Tolosa-Delgado) [link]
- Array of RICH Cells (ARC) is a Cerenkov-based detector
- RICH detectors are suitable for particle identification at high momentum
- Work in geometry optimization, digitization and reconstruction algorithms is ongoing





Innovative Detector for e^-e^+ Accelerator, IDEA

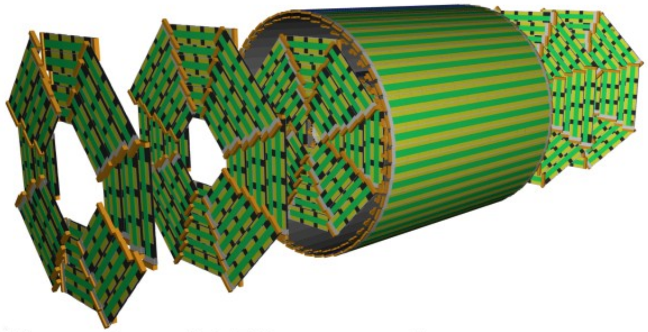
- A lot of activity ongoing, many subdetectors are ready or well advanced
  - Silicon-based vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil inside the calorimeter system



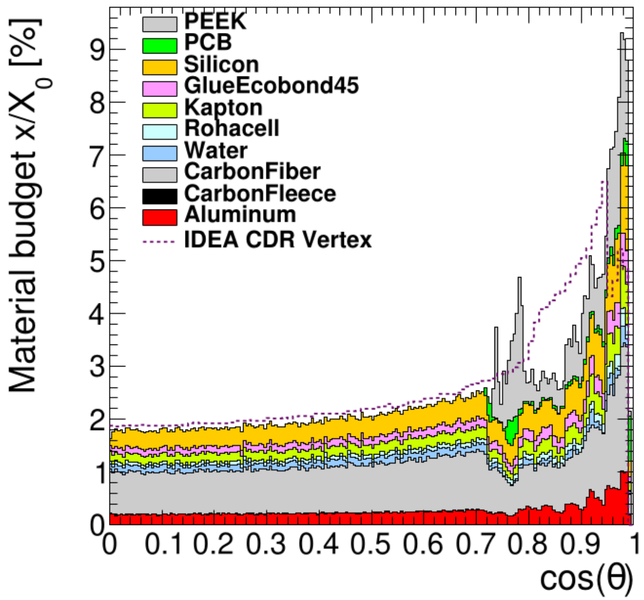
IDEA. Vertex Detector

A. Ilg

- Detector description available from k4geo
- Realistic description of sensors
- Proxy volumes for complex structures (e.g. truss)
- Some support structures are built from CAD design directly
- Lower limit of material budget
- Details about the design will be given tomorrow by F. Palla
- Digitization algorithm in key4hep is ready, reconstruction is still based on Marlin & LCIO data format
- Silicon wrapper subdetector, between the ECAL and Drift chamber, is built by the same detector-type as the Vertex



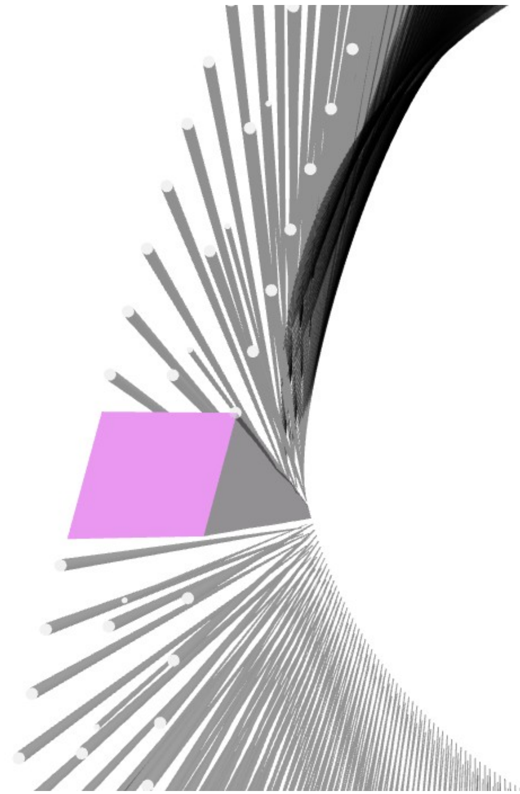
Complete IDEA vertex in DD4hep/Key4hep



IDEA. Drift Chamber

B. Francois

- Ultra-light Drift Chamber, 1-5% X_0
- Tracking efficiency close to 100%
- Angular coverage of 97% 4π
- Geometry description in DD4hep is available, being fine-tuned
- Elemental volume results from intersection of a hyperboloid with rotated tube segment
- F. M. Procacci will overview the status of this subdetector on a dedicated talk later today, together with the last updates on mechanical simulation studies.

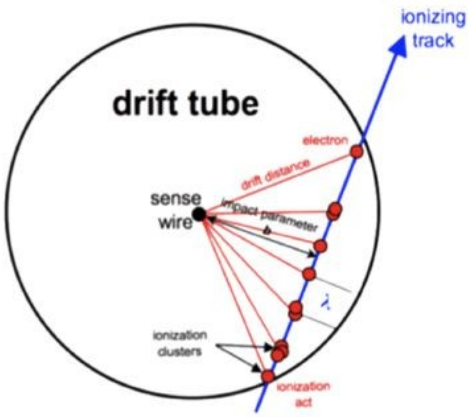


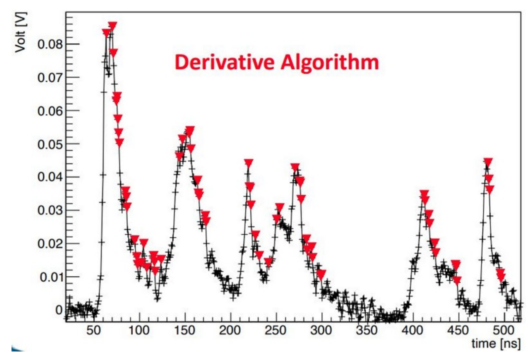
Cross-section of the drift chamber

NB: Wires diameter enlarged by a factor 50 in this picture

IDEA. Drift Chamber. PID capabilities

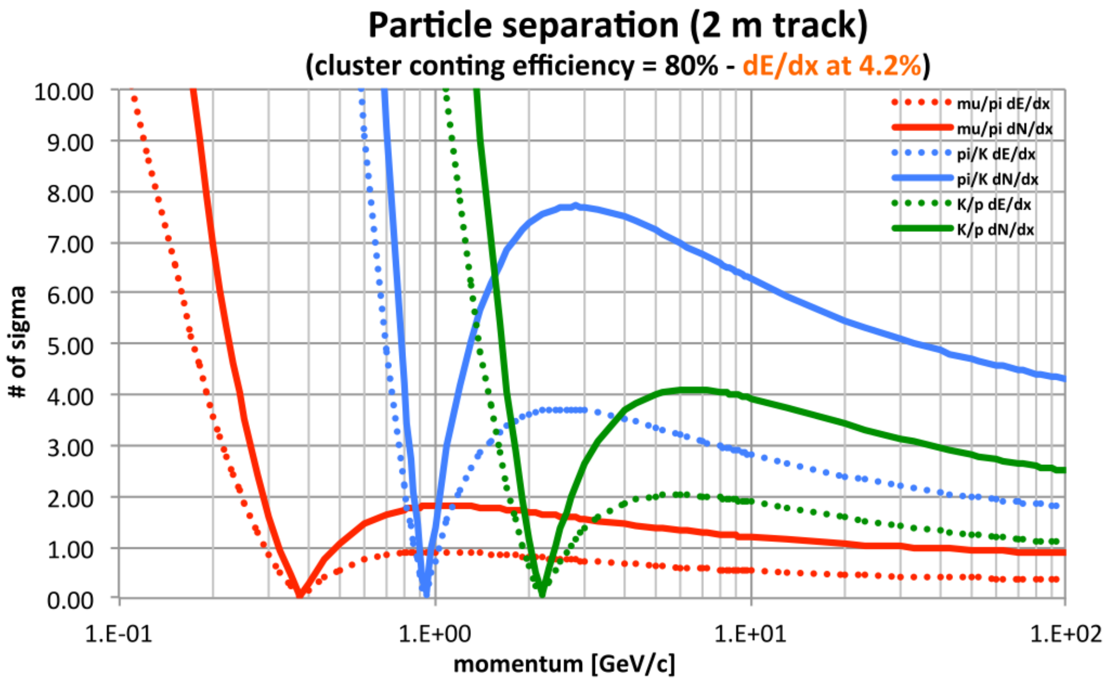
- Smearing the hit positions in local coordinate is ready as part of the digitization process





- Reconstruction algorithm is under development

- Improved PID by cluster-counting technique [arXiv]
  - Energy loss, separation ~2.5%
  - Plus cluster counting ~4.2%

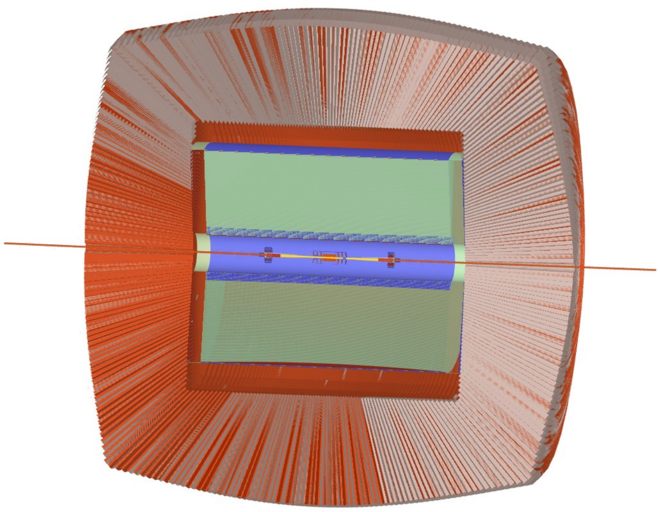


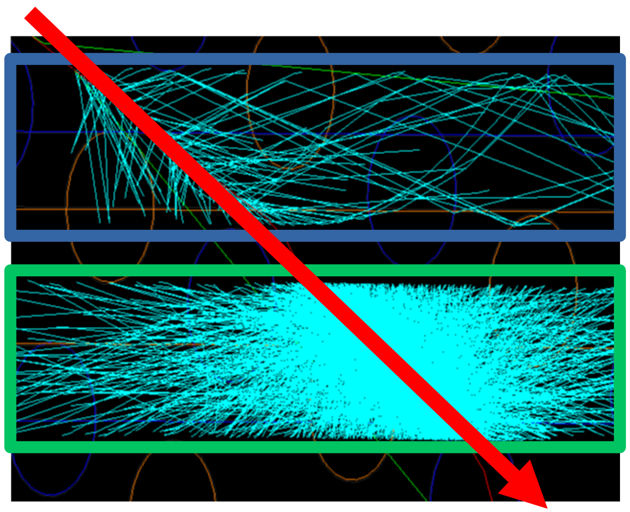
- See W. Elmetenawee presentation for further details about the cluster counting technique and the derived PID based on it

IDEA. Fiber-based Dual Readout Calorimeter

S. H. Ko, S. Kim

- Full-scale 4π projective geometry
- Detector description ready, PR292 in k4geo
- Dedicated fast simulation for optical photons transport
- External library that reproduce the SiPM sensor response already included in key4hep stack
- Preliminary results of the full workflow as standalone
- Work is ongoing
  - “Bucatini” module has been tested at SPS [arXiv], to be implemented in DD4hep
  - Advanced reconstruction using ML, see A. D’Onofrio presentation

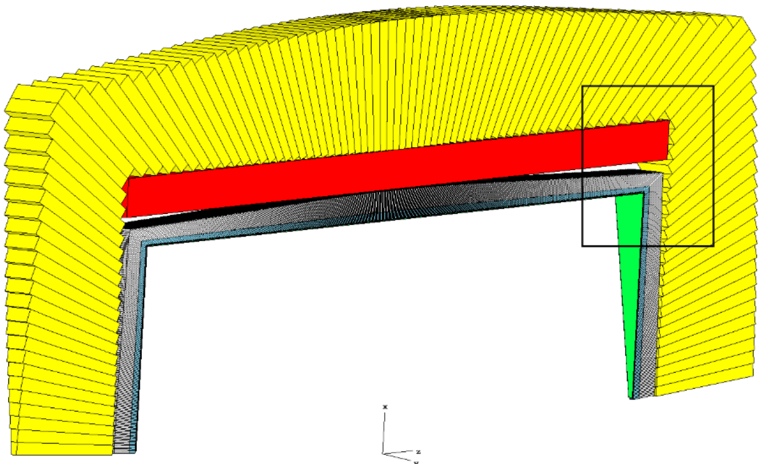




IDEA. Crystal-based Dual Readout Calorimeter

W. Chung

- Crystal-based calorimeter would provide better EM resolution than fiber-based plus longitudinal segmentation [JINST 2020]
- Detector description ready in DD4hep
- Currently working on digitization and reconstruction
- R&D working on new materials [cds]



Fiber-based DRC
Solenoid
Crystal-based DRC

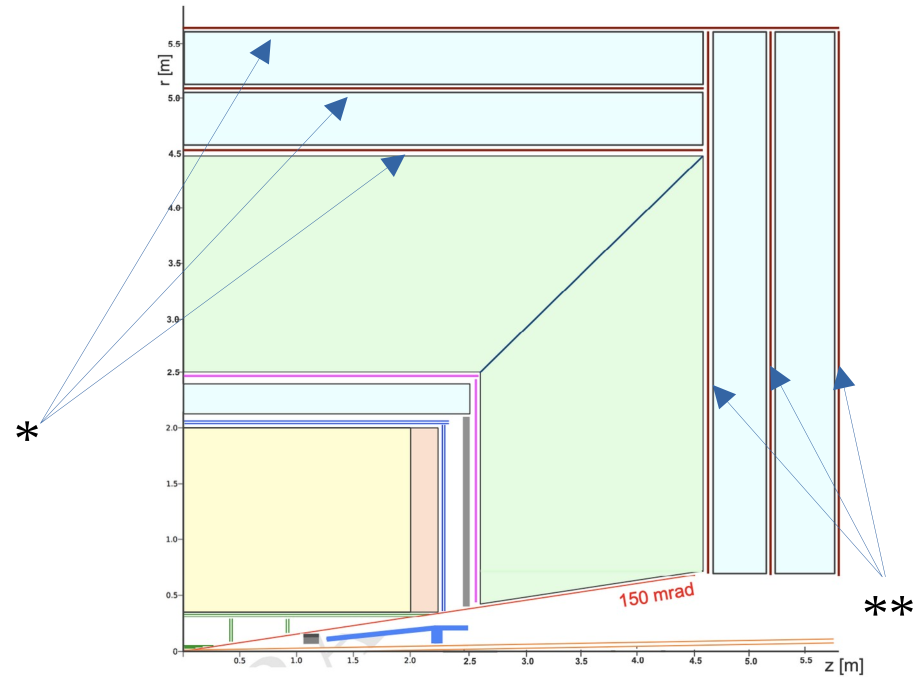
	High granularity Si/W ECAL and scintillator based HCAL	Fiber-based dual-readout calorimeter	Hybrid crystal and dual-readout calorimeter
N. of longitudinal layers	> 40	1	5
ECAL cell cross-section HCAL cell cross-section	25–100 mm^2 100–900 mm^2	2–144 mm^2	100 mm^2 400–2500 mm^2
EM energy resolution HAD energy resolution	$15–25\%/\sqrt{E}$ $45–55\%/\sqrt{E}$	$10–15\%/\sqrt{E}$ $25–30\%/\sqrt{E}$	$\approx 3\%/\sqrt{E}$ $\approx 25–30\%/\sqrt{E}$

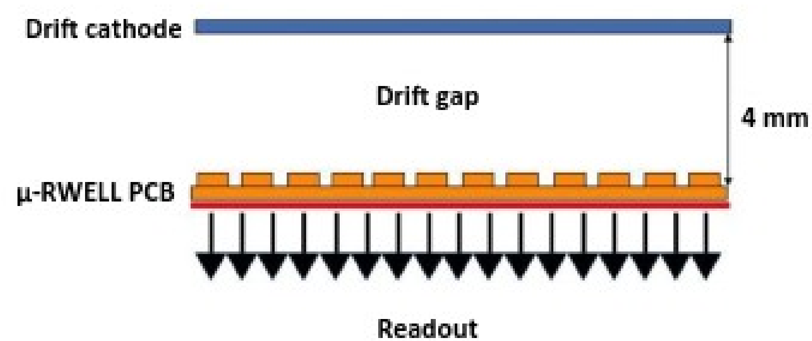
From Geant4 standalone study [JINST 2022]

IDEA. Muon detectors

M. Ali

- Based on uRWELL, a novel single amplification stage Micro-Pattern Gas Detector
- Each uRWELL chamber is 50 x 50 cm^2
- Chambers are grouped in 3 layers of barrel* and endcap**
- The layers are placed between layers of the iron yoke that closes the magnetic field
- Simple geometry ready, implementation based on single chambers it is on the way
- Current work focus on digitization, which simulates the efficiency, fake rate (noise) and resolution according to the R&D results





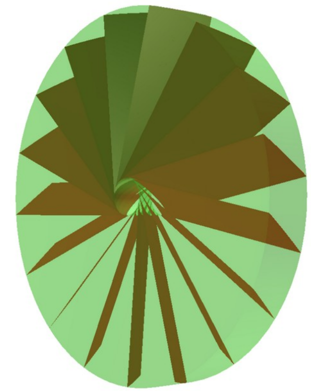
Status of detector implementation. ALLEGRO

A Lepton coLlider Experiment with highly GRanular calorimetry Read-Out

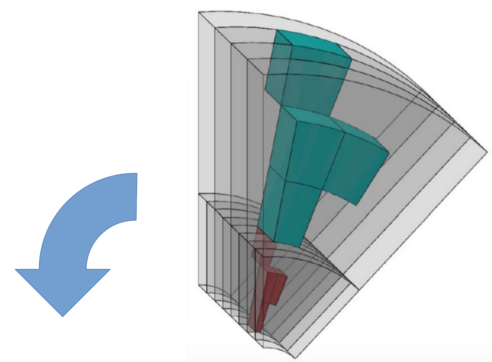
- Vertex detector and drift chamber are adapted from IDEA ones
- Noble liquid-based ECAL
- TileCal as HCAL
- Solenoid between the ECAL and HCAL

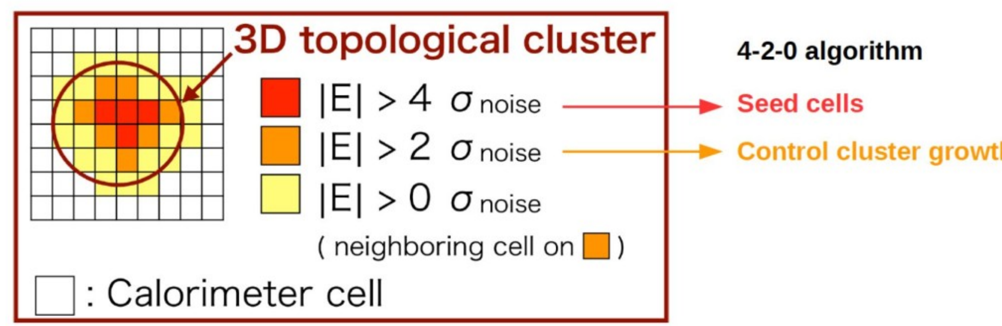
ALLEGRO. Noble liquid-based ECAL

- Implementation of the barrel is ready, and there is a new team working on the endcap implementation with a turbine-like geometry
- Optimization of granularity is ongoing
- New cell segmentation readout in theta is ready (G. Marchiori)
- TopoClustering algorithm [arXiv] is available for the new segmentation in theta
- Noise generation algorithms have to be updated for this new segmentation
- Performance studies to assess the position and energy resolution are being carried out



Endcap geometry, being implemented by E. Varnes and Prof. J. P. Rutherfoord (University of Arizona (US))

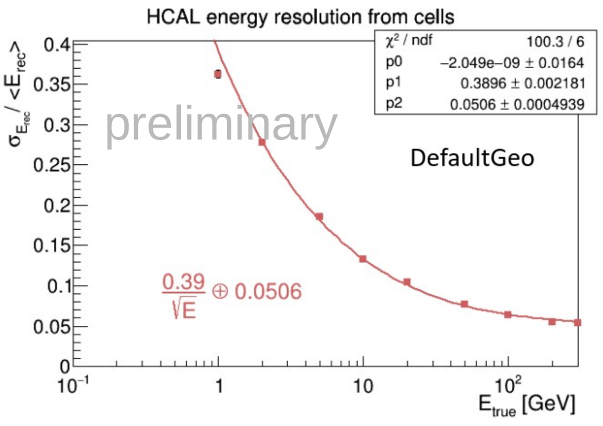


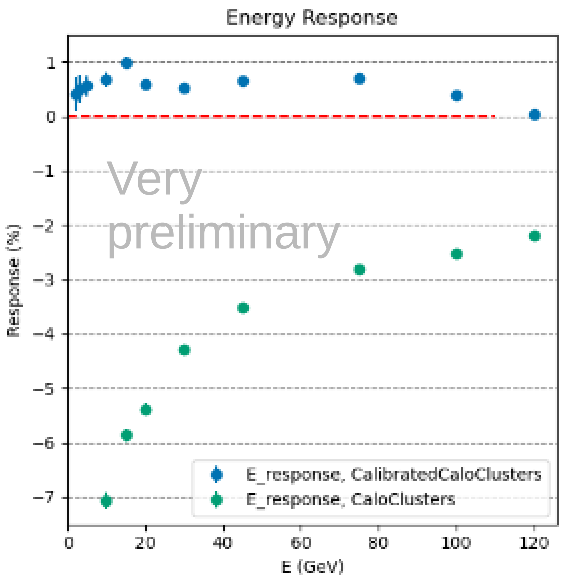


ALLEGRO. TileCal

M. Mlynarikova

- Implementation of HCAL barrel is ready, endcap geometry is being optimized (J. Faltova)
- Combined ECAL+HCAL barrels now under study
  - Optimization of material/geometry
  - Implemented benchmark calibration to calibrate energy deposits to hadronic scale (at the cell level)
  - Sliding window (SW) clustering algorithm works for ECAL+HCAL
  - TopoClustering algorithm works for stand alone ECAL/HCAL, and it is being developed to work with the combination of both
- Ongoing effort for calibration based on MVA (NN) point to better performance (energy resolution and energy response)
- The next steps include as well performance studies, which measure the impact of electronics noise, jet energy scale and resolution, H/W/Z mass resolution





Ancillary steps in the detector fullsim workflow

- In order to test robustness of the simulation studies and their conclusions, more realistic conditions have to be implemented:
  - Overlay of full simulation output with background from the machine, see D. Ntounis presentation about background production
    - Some subdetectors like the IDEA Drift Chamber require more advance studies than simple detector occupancy estimation
  - Regarding the interaction point,
    - some features like Lorentz boost due to the crossing angle and EM field map are already implemented,
    - other features like vertex position offset and its smearing and beam energy spread have to be implemented in key4hep
- We need to validate our simulation (detector description, physics, etc) with test beam data

Summary

- Detector description is centralized in k4geo repository [link]
- A lot of activity ongoing, from detector description to new algorithms for digitization, reconstruction and performance studies
- New software developments driven by detector requirements, like new detector segmentations or implementation of fast simulation for optical photon transport
- Contributions are warmly welcomed
- We are willing to provide support (FCC forum, github, mail)

Backup slides

GDML

- GDML is a file format intended for the interchange of geometries [link]

- Geant4, ROOT and DD4hep can read/write geometries in GDML formats

- DD4hep provides the tool geoConverted, which can convert DD4hep detector description to GDML

```
geoConverter -input mydetector.xml -o mydetector.gdml -compact2gdml
```

- Further details can be found in the section 2.15.2 of DD4hep the manual [link]

- That GDML file can be fed to a Geant4 stand alone application, as it is shown in a dedicated example [link] found under the directory

```
$G4INSTALL/share/Geant4/examples/extended/geometry/vecGeomNavigation/
```