

FCC Detector Models

Physics, Experiments and Detectors
Software and Computing

Alvaro Tolosa-Delgado (CERN)

FCC week 2025, Vienna (Austria)

May. 21th, 2025



- Introduction to detector models
- Software for simulation of detectors in FCC
- Review of subdetectors
- Summary and outlook

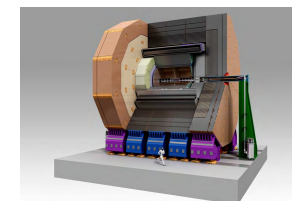
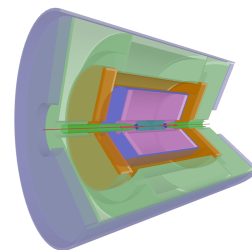
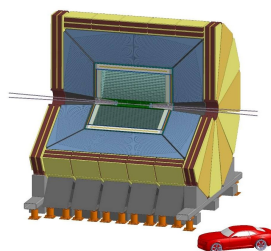
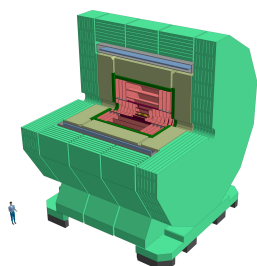
- The FCC design study is entering a more focused and mature phase

- The FCC design study is entering a more focused and mature phase
- Detector concepts are evolving from exploratory ideas to concrete, performance-driven designs
 - The models reflect a convergence of physics goals and technology options [see [M. Dam talk](#) for a detector concepts overview]

- The FCC design study is entering a more focused and mature phase
- Detector concepts are evolving from exploratory ideas to concrete, performance-driven designs
 - The models reflect a convergence of physics goals and technology options [see [M. Dam talk](#) for a detector concepts overview]
- **Simulation plays a central role in guiding design, helping quantify performance and optimize detector technologies**

- The FCC design study is entering a more focused and mature phase
- Detector concepts are evolving from exploratory ideas to concrete, performance-driven designs
 - The models reflect a convergence of physics goals and technology options [see [M. Dam talk](#) for a detector concepts overview]
- **Simulation plays a central role in guiding design, helping quantify performance and optimize detector technologies**
- For comprehensive details on detector geometry, see Chapter 4 of the FCC Feasibility Study Report supporting note [[link](#)]

Introduction to the detector models



Concept	CLD	IDEA	ALLEGRO	ILD
Vertex	Si	Si	Si	Si
Tracker	Si	Gas	Gas	Gas
ECAL/HCAL	Si	Scintillator	Lar / Plastic	Si/Scintillator
Muon syst.	Gas	Gas	Gas	Scintillator
Mag. Field	2T	2T	2T	3.5T
PID	Opt with ARC	Tracker	Tracker	Tracker

Plans for each detector model will be discussed during the PED session on Thursday [[link](#)]

- **Key4hep** is a collaborative, community-maintained software [see [B. Francois talk](#)]
- The simulation workflow spans the full chain: event generation, physics simulation, reconstruction, and analysis

- **Key4hep** is a collaborative, community-maintained software [see [B. Francois talk](#)]
- The simulation workflow spans the full chain: event generation, physics simulation, reconstruction, and analysis
- There are two types of simulation based on the level of detail in the physics modeling:
 - Parametrized simulation (mainly Delphes-based)
 - Detector responses are summarized in "Delphes cards" [link]
 - Allows for quick estimates of physics reach and helps set detector requirements
 - Recently extended to include more accurate tracking and cluster counting, used for training new machine learning-based flavor tagging algorithms

- **Key4hep** is a collaborative, community-maintained software [see [B. Francois talk](#)]
- The simulation workflow spans the full chain: event generation, physics simulation, reconstruction, and analysis
- There are two types of simulation based on the level of detail in the physics modeling:
 - Parametrized simulation (mainly Delphes-based)
 - Detector responses are summarized in "Delphes cards" [link]
 - Allows for quick estimates of physics reach and helps set detector requirements
 - Recently extended to include more accurate tracking and cluster counting, used for training new machine learning-based flavor tagging algorithms
 - High fidelity (full) simulation (Geant4-based)

This talk will focus on Full Simulation (where most of the work ahead lies)

The main software packages used to **perform physics simulations** are:

- Geant4: a Monte Carlo particle transport code

The main software packages used to **perform physics simulations** are:

- Geant4: a Monte Carlo particle transport code
- EDM4hep: a collection of data structures used for persistency in memory

The main software packages used to **perform physics simulations** are:

- Geant4: a Monte Carlo particle transport code
- EDM4hep: a collection of data structures used for persistency in memory
- DD4hep: A comprehensive framework that manages the detector description, including geometry and other functionalities necessary for simulation and reconstruction
 - Detector **geometry description is the primary input** for performing simulations, as Geant4 provides built-in physics*, and DD4hep the mechanisms to record and write simulation data

*High-precision measurements require highly accurate simulations: improving and validating physics models in Geant4 is essential to achieving the FCC's physics goals

- Each detector concept is described by a text file called **compact file**
- This text file contains:
 - › specific configuration of each subsystem, such as its size, number of layers, materials, etc
 - › global configuration, including list of materials, fields description, etc

Compact file

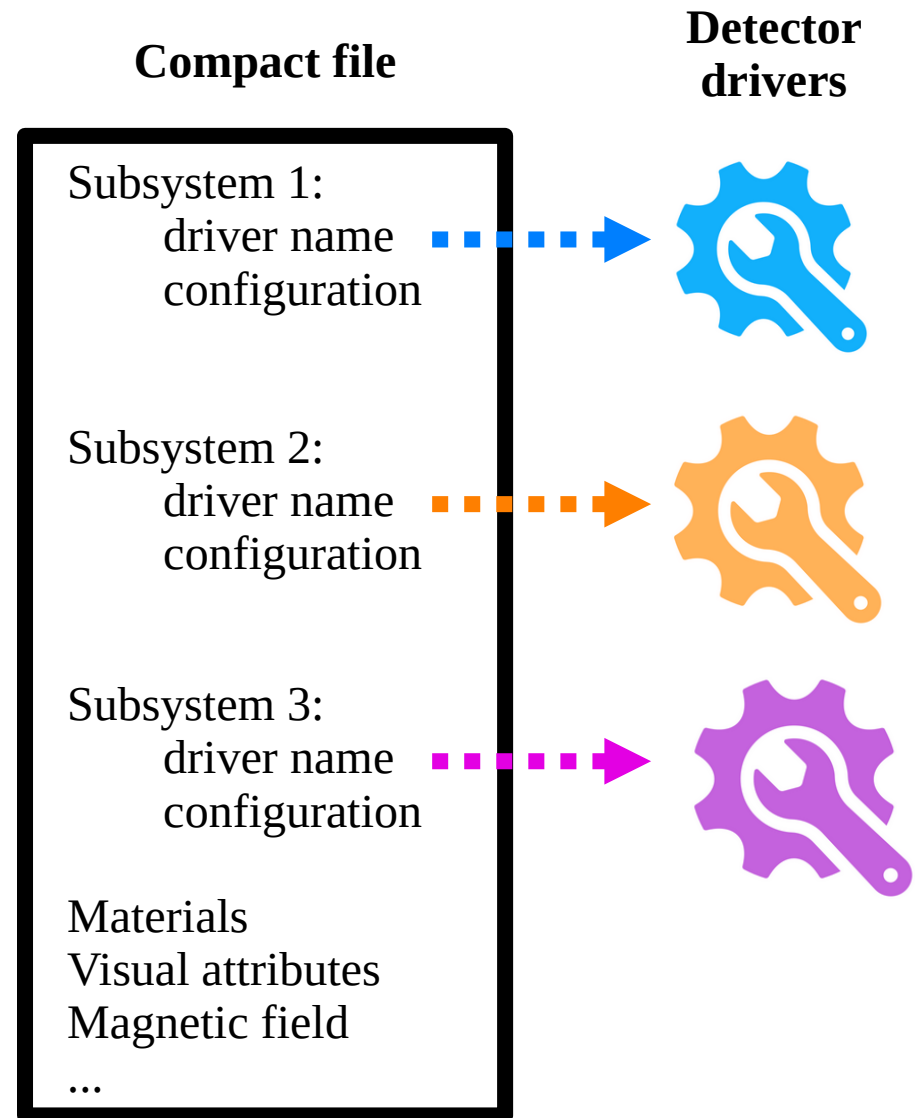
```
Subsystem 1:  
  driver name  
  configuration
```

```
Subsystem 2:  
  driver name  
  configuration
```

```
Subsystem 3:  
  driver name  
  configuration
```

```
Materials  
Visual attributes  
Magnetic field  
...
```

- Each detector concept is described by a text file called **compact file**
- This text file contains:
 - specific configuration of each subsystem, such as its size, number of layers, materials, etc
 - global configuration, including list of materials, fields description, etc
- Each subsystem configuration links to a **detector driver**, which builds the detector geometry in memory according to the given configuration



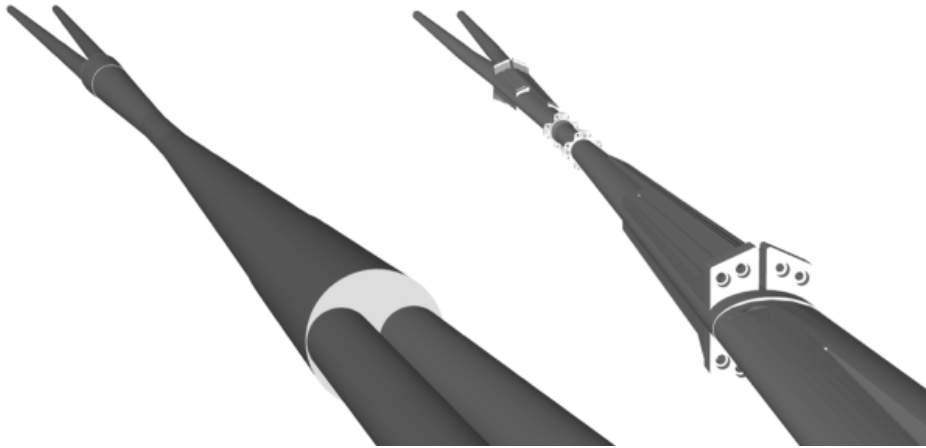
- DD4hep allows for easy swapping of subdetectors
 - Detector drivers are reusable across concepts, only the configuration file changes
- This motivated **detector descriptions to be centralized in k4geo [\[link\]](#), a repository part of the Key4hep GitHub project**

- DD4hep allows for easy swapping of subdetectors
 - Detector drivers are reusable across concepts, only the configuration file changes
- This motivated **detector descriptions to be centralized in k4geo [\[link\]](#), a repository part of the Key4hep GitHub project**
- In the following, I will review the subdetectors proposed for FCC, grouped as:
 - Machine-Detector Interface (MDI)
 - Tracking Systems: Silicon-based and Silicon/Gas-based designs
 - Calorimeter Systems: sampling calorimeters and dual-readout calorimeters
 - Muon Systems: different implementations of RPC chambers
 - Particle Identification (PID) system

- DD4hep allows for easy swapping of subdetectors
 - Detector drivers are reusable across concepts, only the configuration file changes
- This motivated **detector descriptions to be centralized in k4geo [\[link\]](#), a repository part of the Key4hep GitHub project**
- In the following, I will review the subdetectors proposed for FCC, grouped as:
 - Machine-Detector Interface (MDI)
 - Tracking Systems: Silicon-based and Silicon/Gas-based designs
 - Calorimeter Systems: sampling calorimeters and dual-readout calorimeters
 - Muon Systems: different implementations of RPC chambers
 - Particle Identification (PID) system
- This list is not exhaustive; some subdetectors are defined outside Key4hep
 - We welcome collaboration with teams developing new subdetectors and encourage integration of these efforts into the Key4hep ecosystem

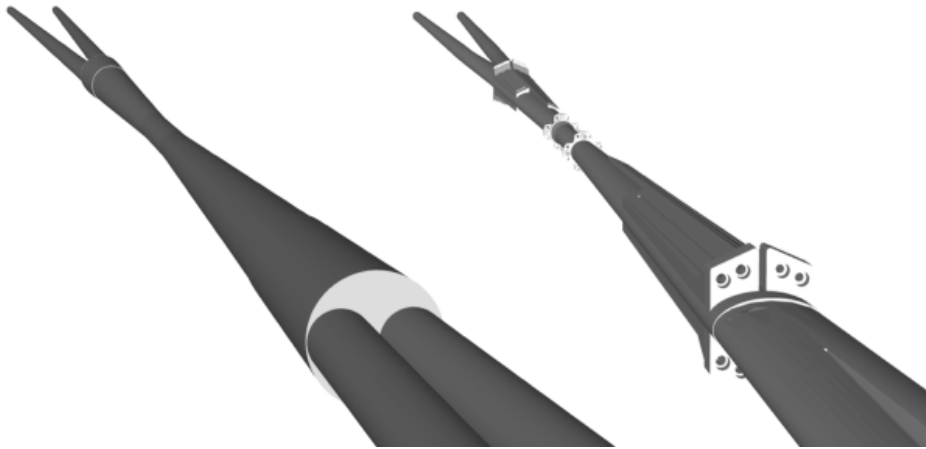
- MDI design is driven by the nature of the colliding beam
 - Shared description of MDI among FCC detector models

- MDI design is driven by the nature of the colliding beam
 - Shared description of MDI among FCC detector models
- Beampipe structure is non sensitive, but detailed description is needed for accurate simulation results
 - baseline model is made up by simple geometrical shapes
 - detailed CAD design has newly been developed

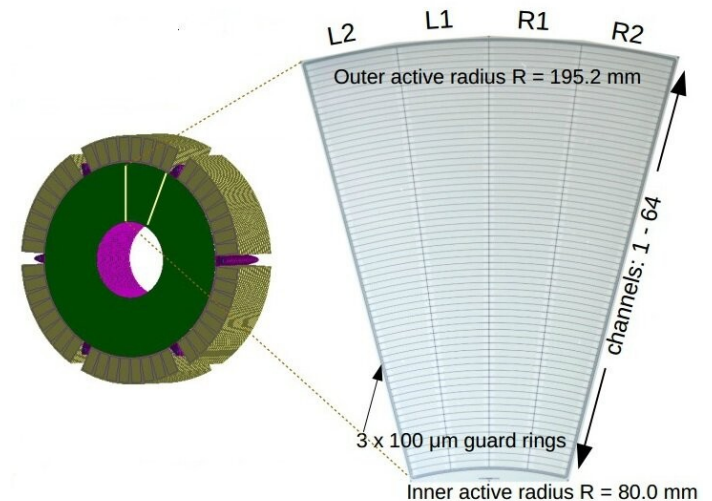


Shape-based model (left) and CAD model (right)
of the FCC beampipe

- MDI design is driven by the nature of the colliding beam
 - Shared description of MDI among FCC detector models
- Beampipe structure is non sensitive, but detailed description is needed for accurate simulation results
 - baseline model is made up by simple geometrical shapes
 - detailed CAD design has newly been developed
- Lumimeter: a silicon-tungsten (SiW) calorimeter based on the one used by LEP-OPAL

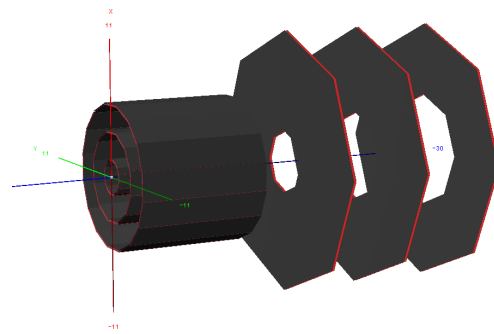


Shape-based model (left) and CAD model (right)
of the FCC beampipe

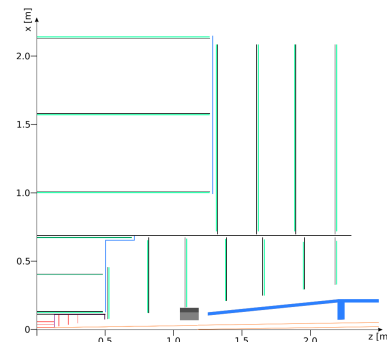


Lumimeter geometry

- The tracking system consists of a **full silicon vertex and tracker**, covering both the barrel and endcap
- Detector driver build geometry as assemblies of radial or planar layers
- Tracking layers can be resized by editing just a few lines in the compact file
 - Enabled rapid development of a new CLD variant with an additional PID subsystem (see later slides)
- The **maturity of the geometry has paved the way for further developments**, such as the ongoing integration of ACTS with the CLD tracking system

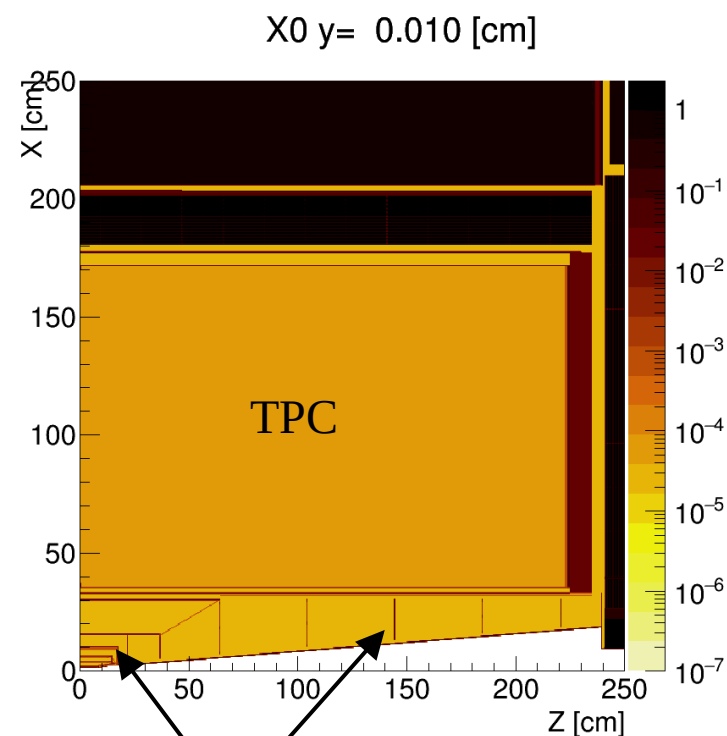


CLD vertex



CLD tracker

- The system combines a **silicon vertex and inner tracker with a TPC** as the main tracker
- This configuration was originally developed by ILD (TDR, 2013), for ILC project
- The silicon vertex geometry is an evolved, more detailed version of the CLD vertex
- The TPC design is actively developed by the LC-TPC collaboration, and is part of CERN's DRD1 program
- A new geometry version tailored for FCC has been developed. See V. Schwan talk [\[link\]](#)
 - This version is under study to assess beam-induced backgrounds. See D. Jeans talk [\[link\]](#)



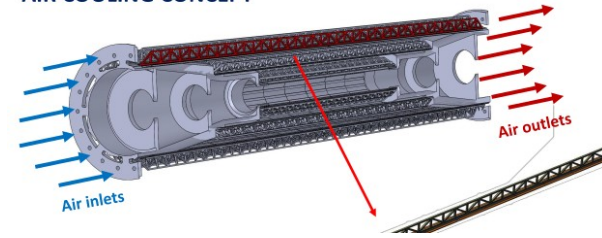
Vertex and inner silicon trackers

ILD cross section view of the vertex and TPC

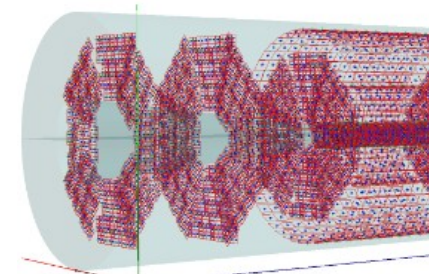
Silicon + gaseous (Drift Chamber) tracking

- This combination of **silicon vertex and drift chamber** is used by IDEA and ALLEGRO concepts
- A **newly developed vertex detector driver**
 - Follows design used for ALICE ITS-3
 - Geometry ready for simulation
 - Easy reuse across different detector configurations
 - Also used by the Silicon Wrapper subsystem

AIR COOLING CONCEPT



Vertex support structure

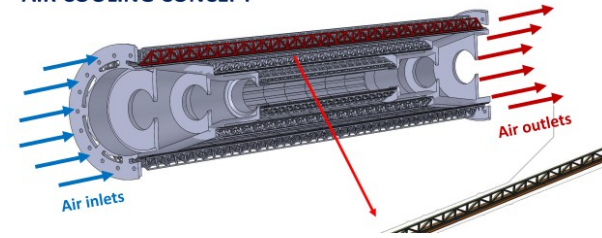


Vertex sensitive surfaces

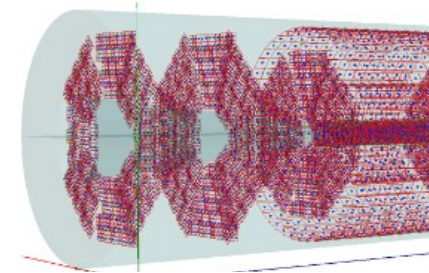
Silicon + gaseous (Drift Chamber) tracking

- This combination of **silicon vertex and drift chamber** is used by IDEA and ALLEGRO concepts
- A **newly developed vertex detector driver**
 - Follows design used for ALICE ITS-3
 - Geometry ready for simulation
 - Easy reuse across different detector configurations
 - Also used by the Silicon Wrapper subsystem
- **IDEA full stereo drift chamber (DC)**
 - Geometry description ready, but Geant4 physics has to be tuned and validated against beam test data for accurate simulations
 - Preliminary background studies and development of new tracking algorithms are already using this implementation. See A. De Vita talk [\[link\]](#)

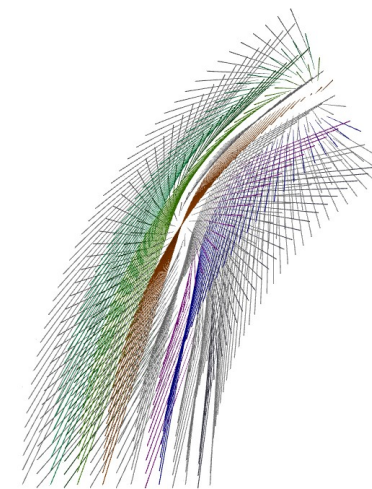
AIR COOLING CONCEPT



Vertex support structure



Vertex sensitive surfaces



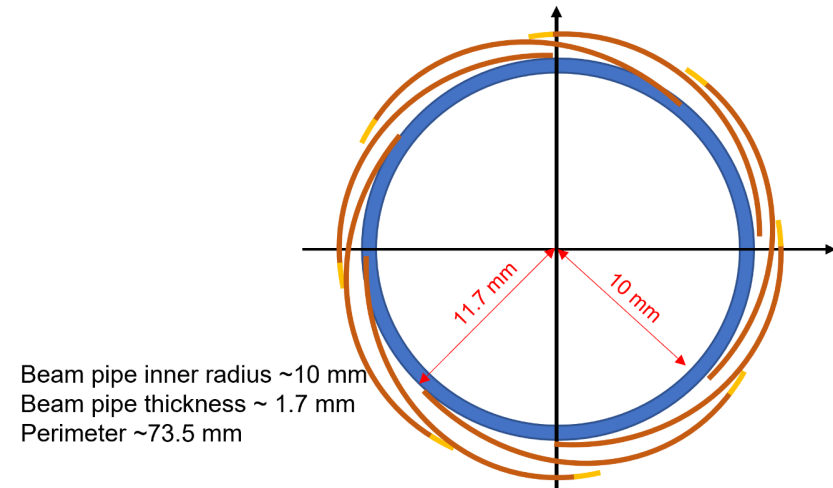
Cross-section of the wires (software)



MEG II, a similar design of a DC

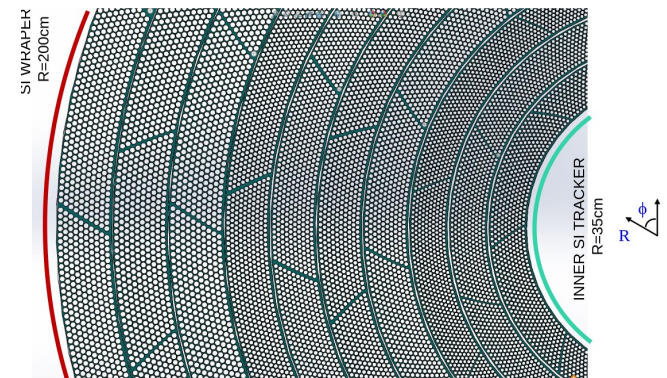
- **Schenecke (Snail-shaped) vertex detector, SEED**

- Design based on bend ladders, more flexibility (radius, stitching, resolution, etc) than ALICE ITS-3 like vertex presented in previous slide
- Competitive material budget and small (1 cm) radius of the first hit for the whole azimuthal acceptance is valuable for all detector concepts
- Implementation for full simulation is ongoing



- **Straw tube tracker**

- Description in DD4hep available
 - Design parameters yet to be optimized
- Current proposed stereoangle is smaller than DCH, leading to bigger uncertainty in Z position



Axial cut of the straw tube subdetector

$$\sigma_z = \sigma_{xy} / \sin(\alpha_{stereo})$$

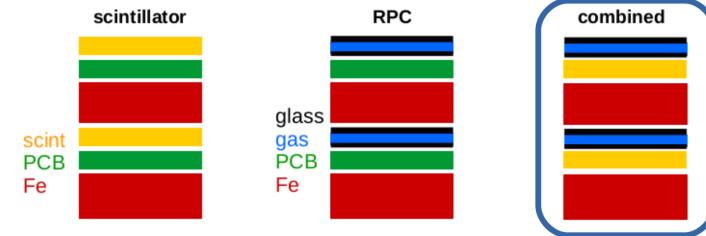
General sampling calorimeter

- Consist in a layered structure covering the barrel and endcap regions.
- The same detector driver is used to build the ECAL and HCAL of CLD
 - The layer structure is given in the compact file
 - Geometry is ready in k4geo repository
- ILD calorimeters are similar to CLD's
 - Smart implementation that allows to simulate up to five configurations of different detector technologies in one single run
 - Geometry is also available in k4geo
- See review talk by V. Boudry [[link](#)]



CLD outer systems:

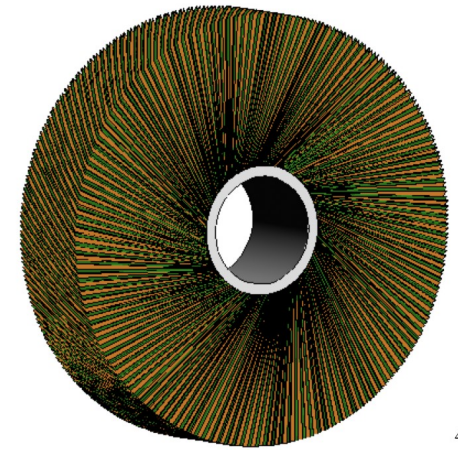
1. ECAL
2. HCAL
3. Iron Yoke with RPC for muon ID
4. solenoid



ILD calorimeter

- These calorimeters used by ALLEGRO detector concept
- **Noble liquid ECAL full detector geometry is ready**
 - Crosstalk effects implemented for the barrel region, ongoing work to extend them to the endcap
 - Data extensions in place, ready for Pandora reconstruction
 - Review talk by Z. Wu talk [[link](#)]

3:

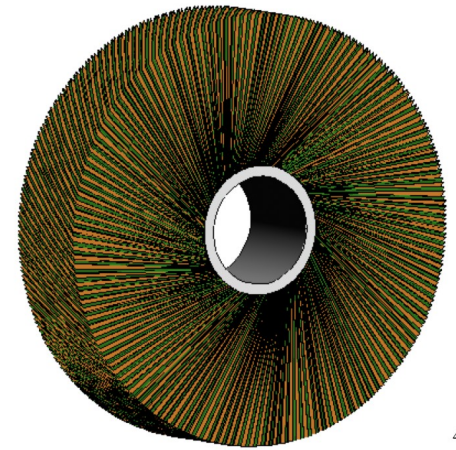


4

Noble liquid ECAL endcap

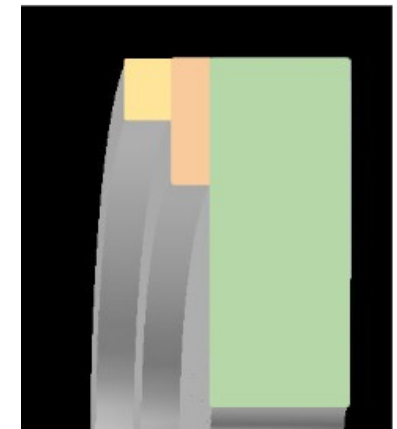
- These calorimeters used by ALLEGRO detector concept
- **Noble liquid ECAL full detector geometry is ready**
 - Crosstalk effects implemented for the barrel region, ongoing work to extend them to the endcap
 - Data extensions in place, ready for Pandora reconstruction
 - Review talk by Z. Wu talk [\[link\]](#)
- **TileCal complete detector geometry is also ready**
 - Two new segmentations, phi-theta and phi-row
 - Calculation of neighbour cells for TopoClustering algorithm
 - Current developments on optimizing the reconstruction steps

3:



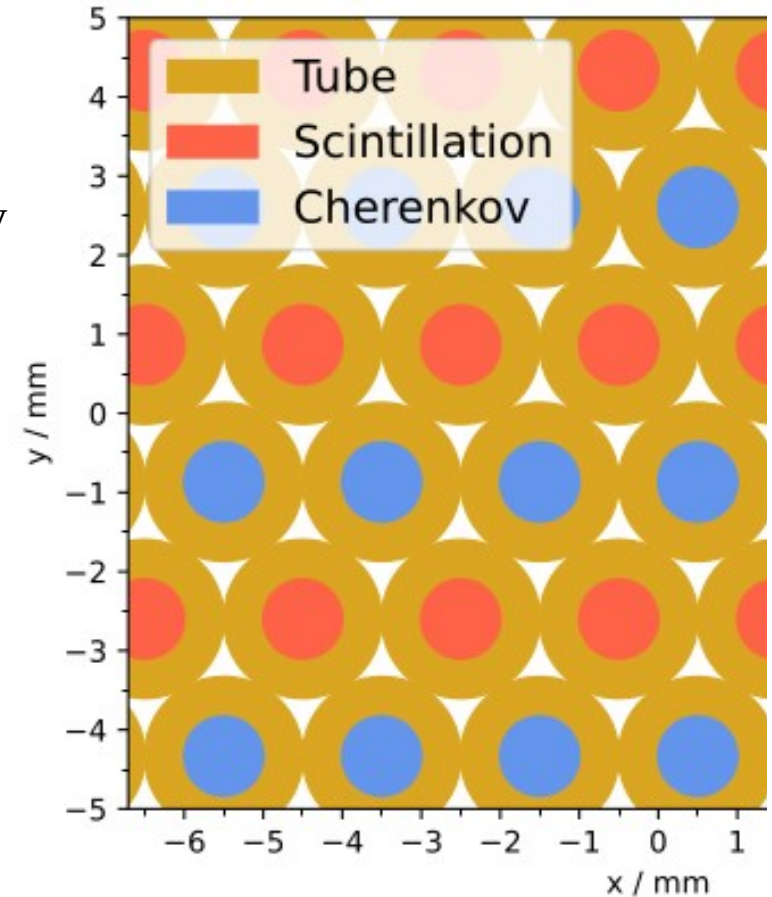
4

Noble liquid ECAL endcap



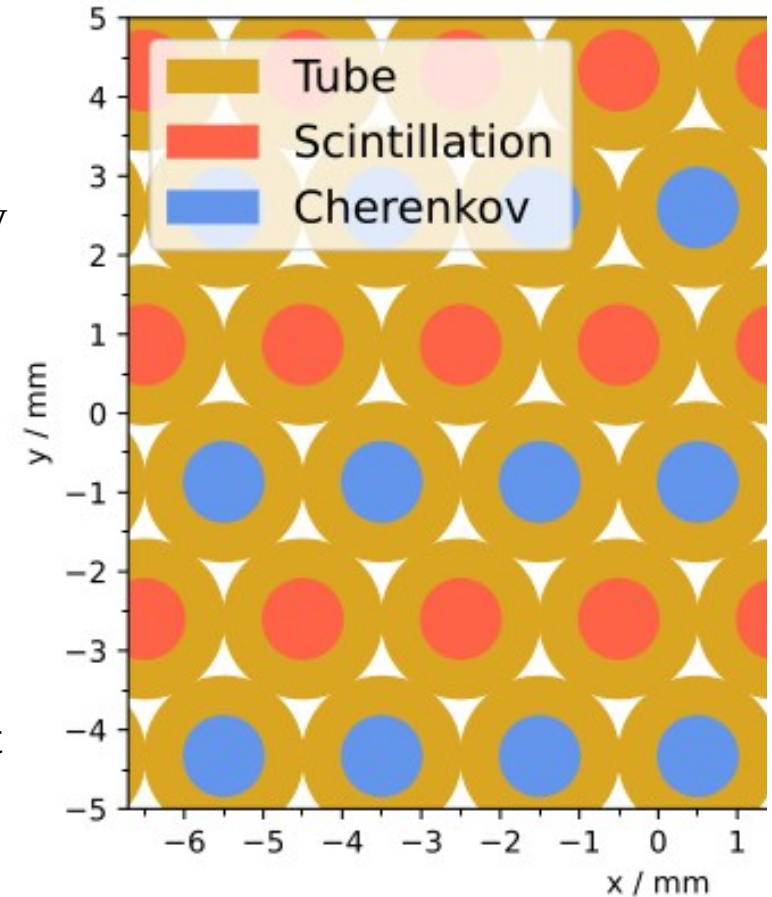
TileCal endcap

- This subdetector is so far specific to IDEA detector concept
- Monolithic /Fiber options, depending on the absorber matrix
- **Geometry** and Geant4 physics models have been thoroughly validated, **ready to be used**
- Due to its complexity, it requires dedicated developments:
 - Custom functionality to record optical photon information
 - A fast simulation for photon transport within the fibers



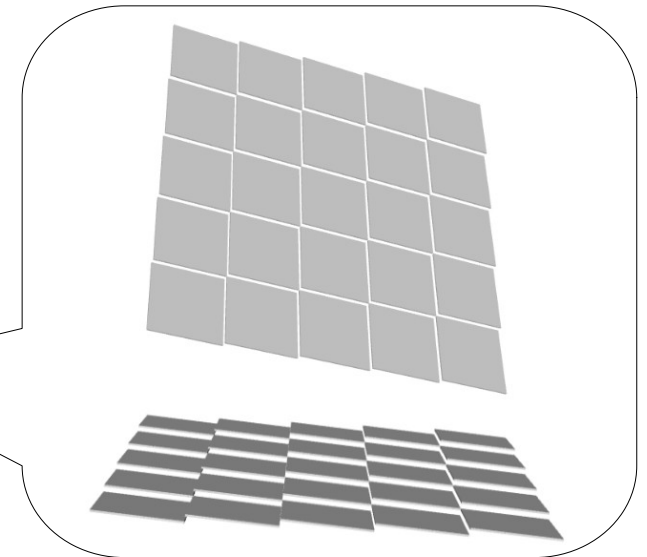
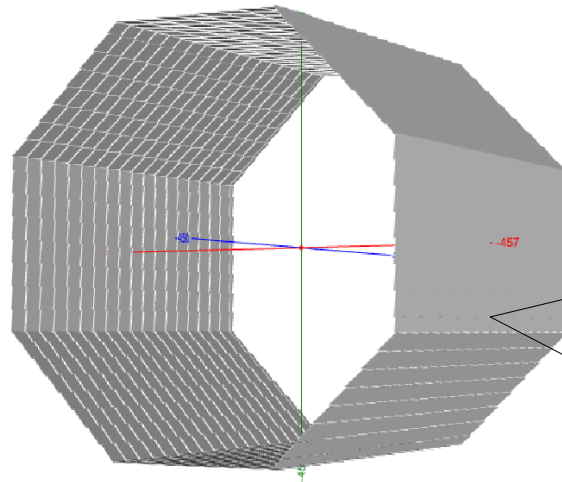
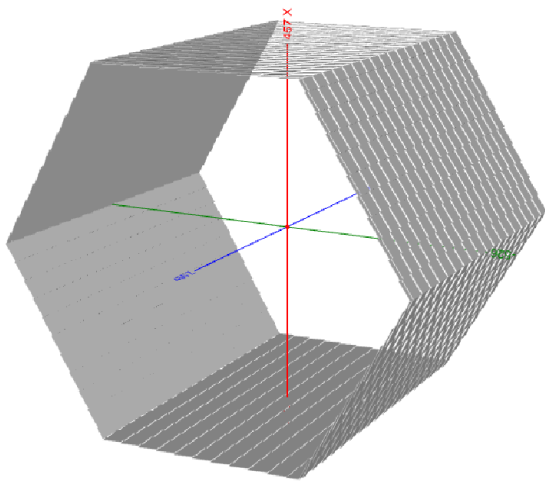
Cross-section of the DRC,
capillary option [[link](#)]

- This subdetector is so far specific to IDEA detector concept
- Monolithic /Fiber options, depending on the absorber matrix
- **Geometry** and Geant4 physics models have been thoroughly validated, **ready to be used**
- Due to its complexity, it requires dedicated developments:
 - Custom functionality to record optical photon information
 - A fast simulation for photon transport within the fibers
- An additional option includes a **crystal-based dual-readout** ECAL placed in front of the main calorimeter, providing excellent EM resolution
 - [Open Pull Request](#) to k4geo, close to be completed
- See review talk by B. Hirosky [[link](#)]



Cross-section of the DRC, capillary option [[link](#)]

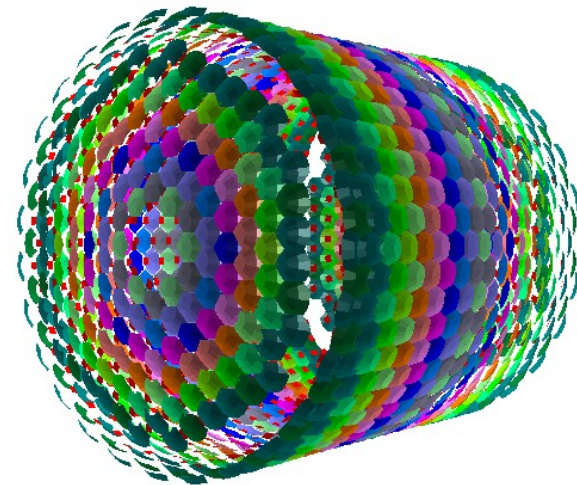
- Detector geometry of the instrumented iron yoke with **Resistive Plate Chambers** (RPC) is built by the same **generic calorimeter detector driver** used for CLD calorimeters
- More detailed **uRWELL-based systems are available k4geo**
 - Flexible configuration (number of sides, sizes of the chamber, overlap area for hermeticity)
 - Same driver used to build the IDEA muon system and pre-shower detector
 - It also allows to attach reconstruction surfaces by the DD4hep generic surface plugin
- Alternative muon systems covered by B. Zhou talk [\[link\]](#)



Detailed muon systems, based on uRWELL chambers
Courtesy of M. Ali

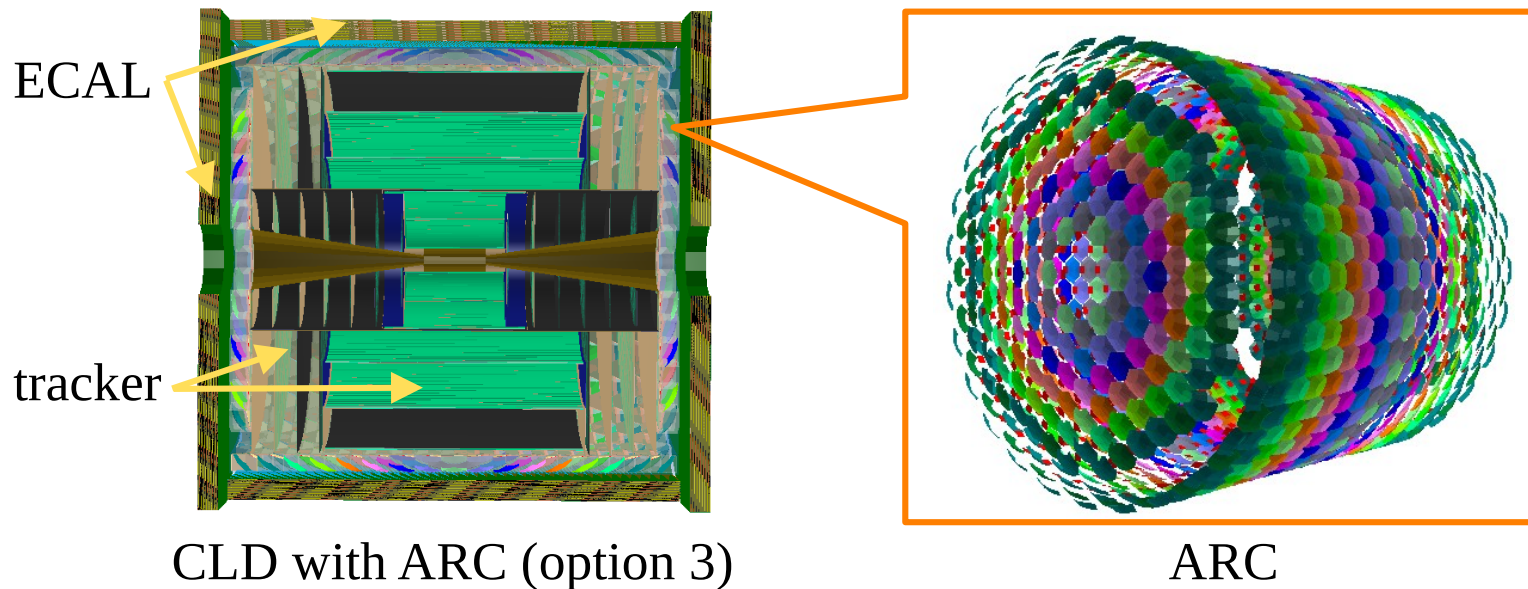
A custom overlap area is achieved by tilting the chambers

- The **ARC** detector provides Particle Identification based on the RICH technique
 - It has been **fully implemented in DD4hep and available in k4geo**



ARC

- The **ARC** detector provides Particle Identification based on the RICH technique
 - It has been **fully implemented in DD4hep and available in k4geo**
- **New CLD option** with a smaller tracker compared to baseline incorporates the ARC
 - Performance of this tracker was presented at LCWS 2024 by G. Sadowski [[link](#)]
- Current status of the ARC performance studies is presented by S. Pezzulo [[link](#)]



- In this talk, I've reviewed the diverse range of (sub)detector being explored for the FCC
 - With a focus on those for which detailed geometries are already implemented and ready for use
- **DD4hep**-based geometries provide **interoperability** and flexibility
- Centralizing all geometries in the k4geo repository is crucial for maintainability, testing, and reuse
- Input from detector R&D and beam tests remains essential to validate and tune full simulation configurations

- With many geometries now in place, reconstruction software can be further developed and tested
- The next phase will require:
 - Tuning of simulation parameters for realism and consistency
 - Performance optimization of simulation software
 - Engineering refinements to detector designs
- **Collaboration with DRD efforts, detector (proto)collaborations, and core software projects (Geant4, ROOT, DD4hep) will be key**
- The open, modular design of Key4hep and k4geo enables active development, welcomes new contributors, and illustrates how open software practices can accelerate the development cycle

