Simulation of Higgs, Electroweak and Top Factories detectors

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Third ECFA Workshop on e+e- Higgs, Electroweak and Top Factories, Paris (France)

Oct. 10th, 2024

Outline

- Introduction to detector families
- Software for simulation of detectors at future colliders
- Review of subdetectors
- Outlook

Introduction to the detector families

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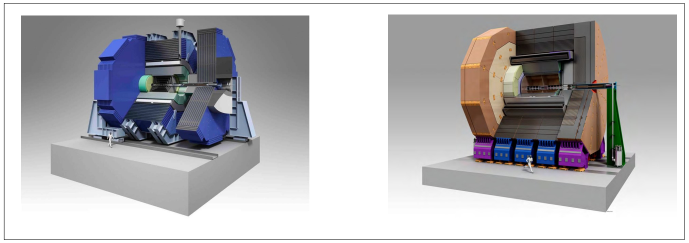
- Different detector concepts are being developed, where **simulation is the key to identify the ones that maximize physics performance**
  - ➢ Simulation involves a chain of steps, including Monte Carlo (MC) particle generation, physics processes simulation, event reconstruction, and data analysis
- The ECFA Report will provide more details in its Simulation section

Introduction to the detector families

ILC



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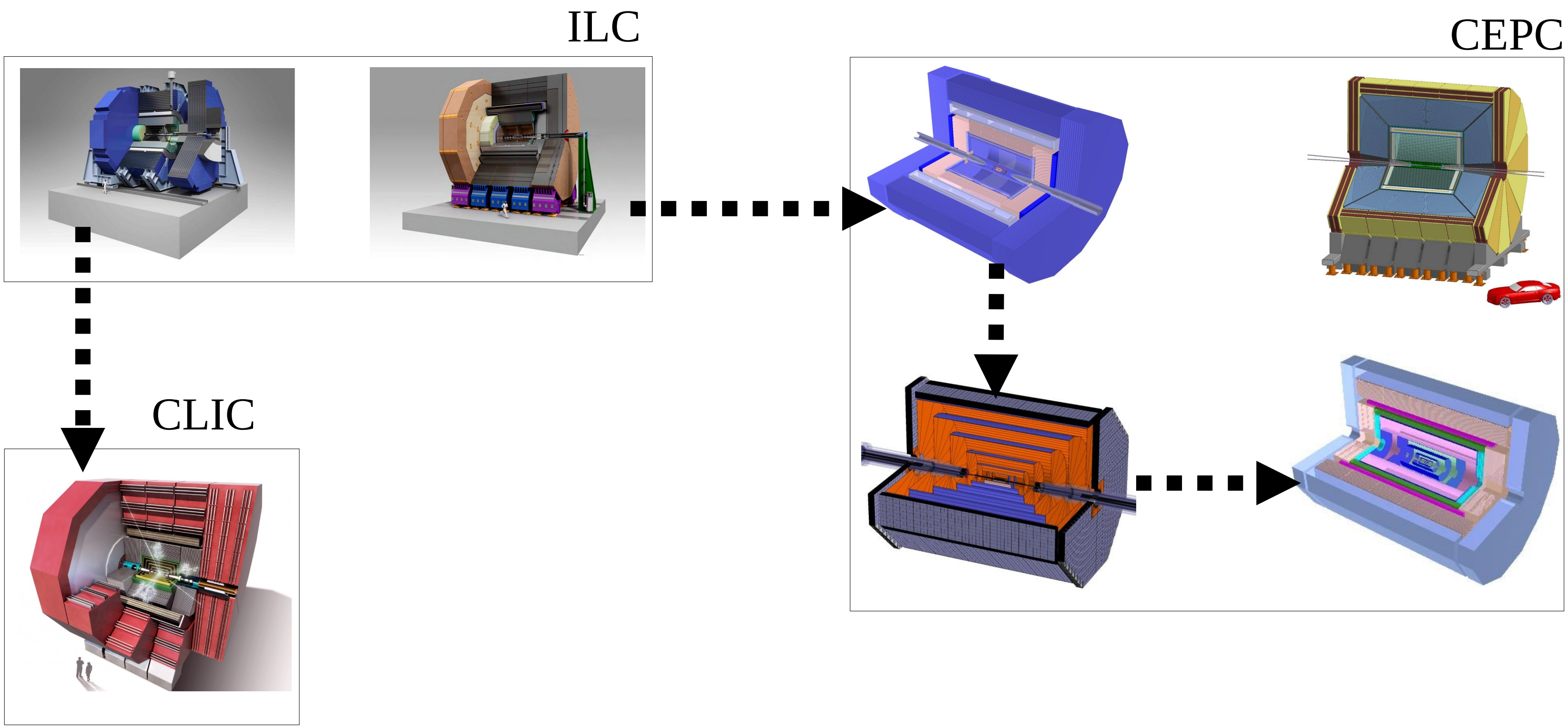

The arrows show the historical evolution of some detector concepts

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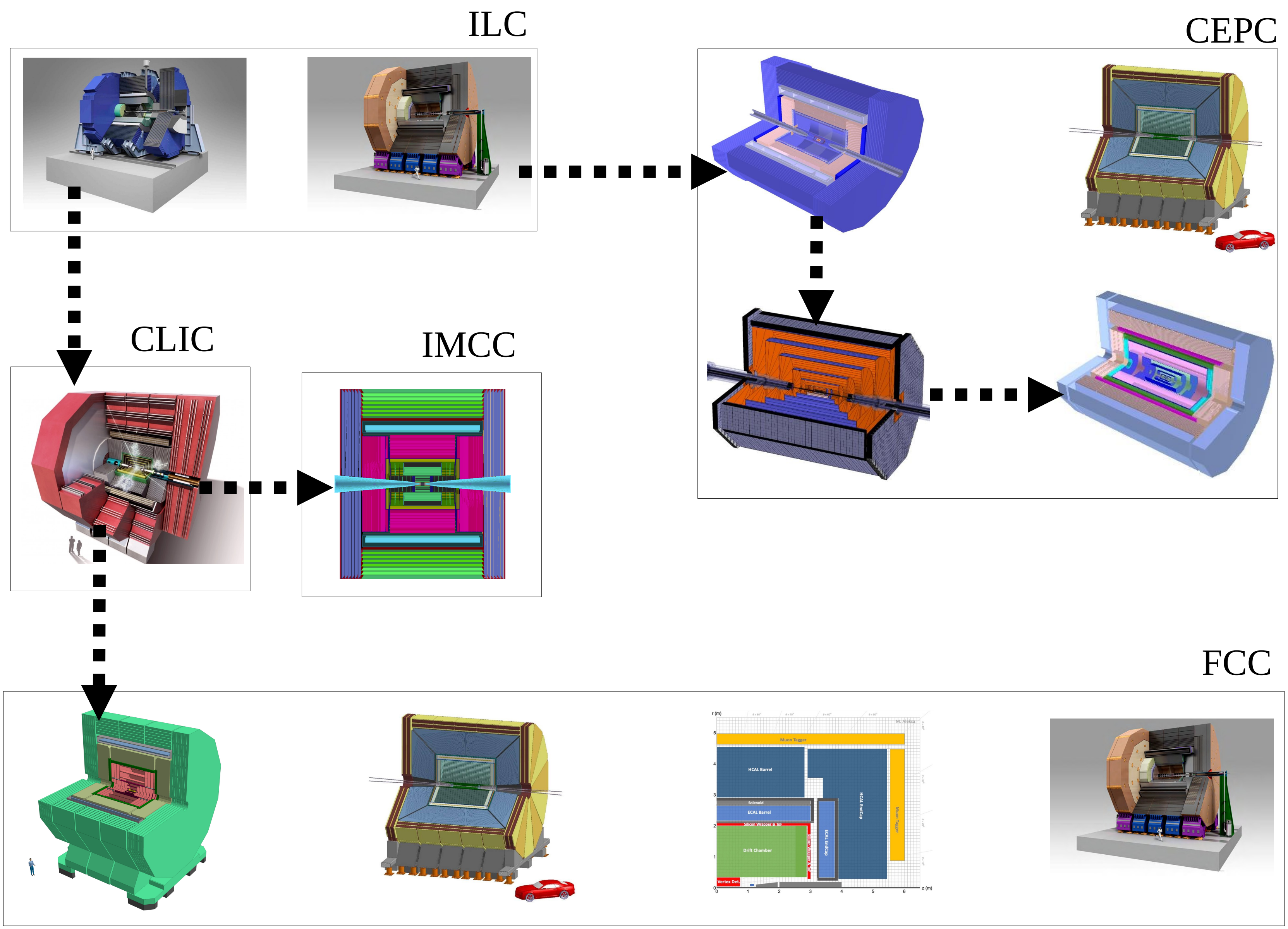

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  - Parametrized simulation (mainly Delphes-based)
    - Detector responses are summarized in "Delphes cards," available for FCC, CLIC, ILC, and MuonCollider detectors [link]
    - Allows for quick estimates of physics reach and helps set detector requirements
      - Seamless generation of samples for many different detector scenarios
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This talk will focus on Full Simulation (where most of the work ahead lies)

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- 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

DD4hep for detector geometry description

- 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:
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Subsystem 3:
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Materials
Visual attributes
Magnetic field
...

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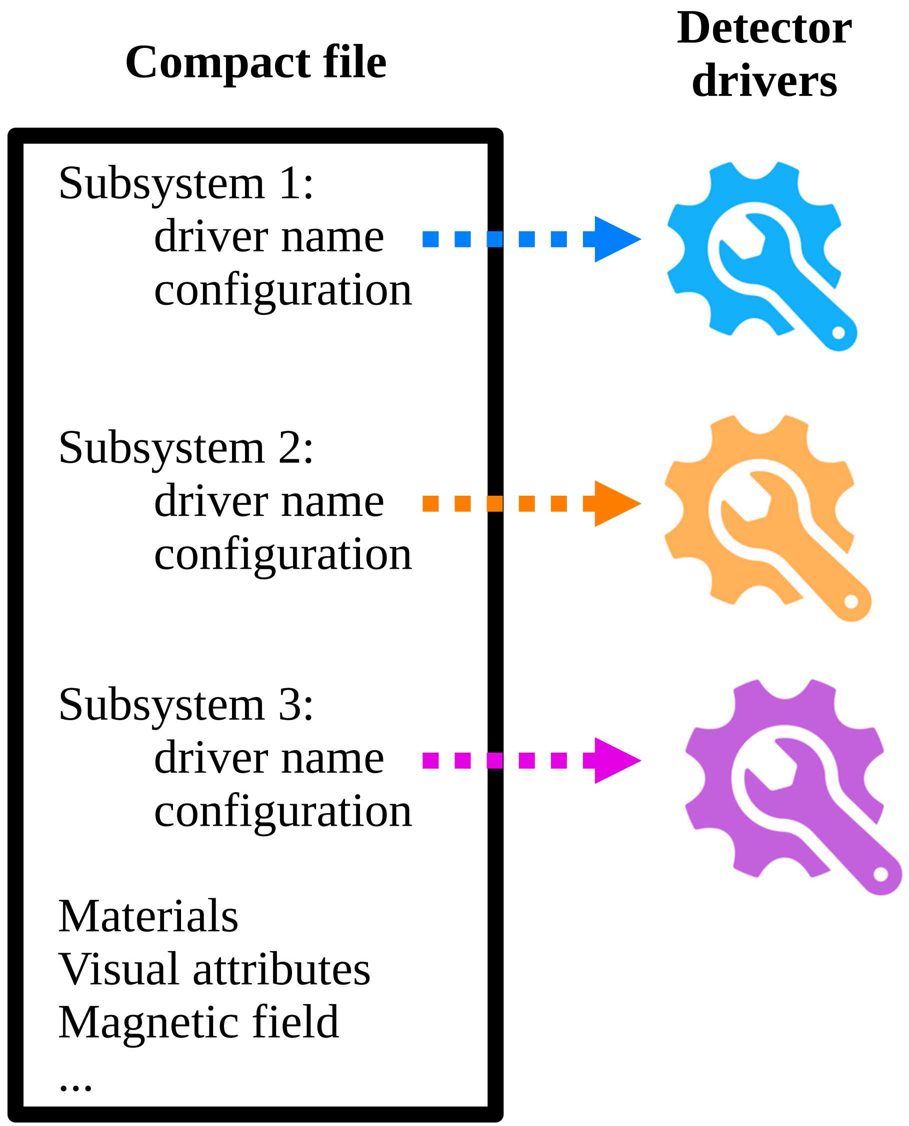
- Each subsystem configuration links to a **detector driver**, which builds the detector geometry in memory according to the given configuration



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  - In the following, I will review the subdetectors hosted in k4geo
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- The subsystems are 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
  - Particle Identification (PID) system

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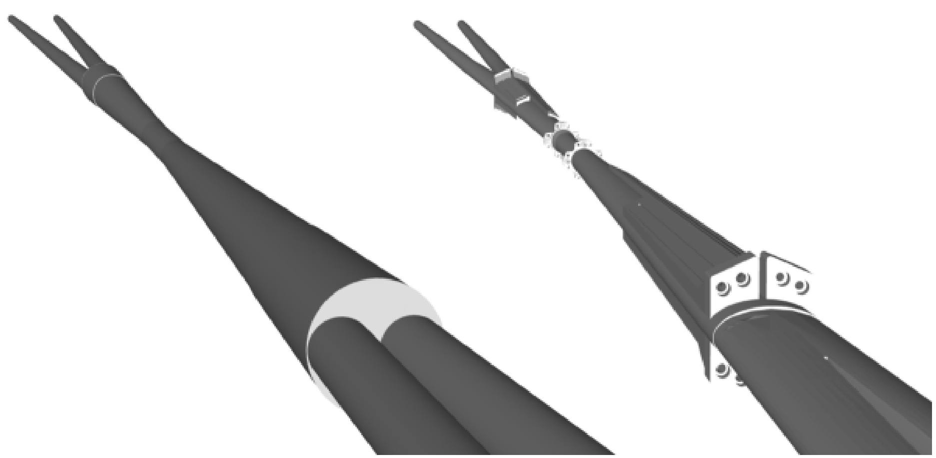

Shape-based model (left) and CAD model (right)
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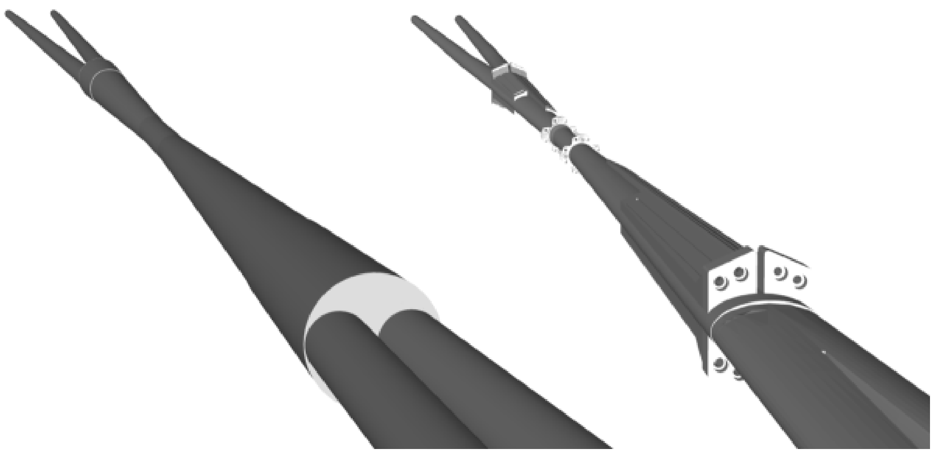
- Lumimeter: a silicon-tungsten (SiW) calorimeter based on the one used by LEP-OPAL. At the moment the same detector driver is used by detectors at ILC, CLIC, and FCC.



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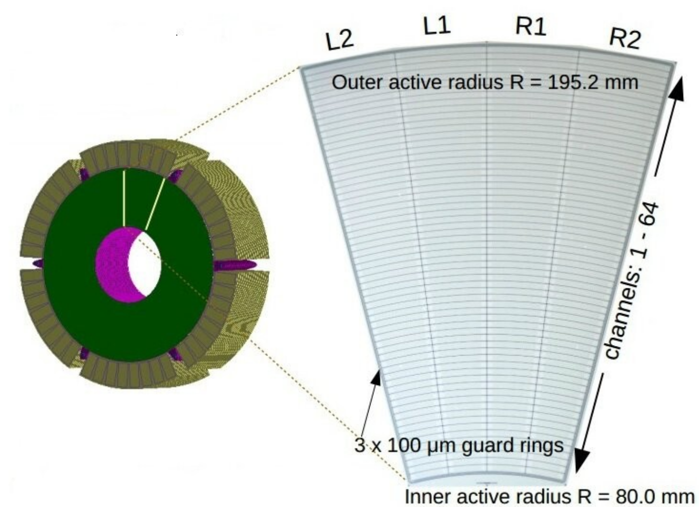

Lumimeter geometry

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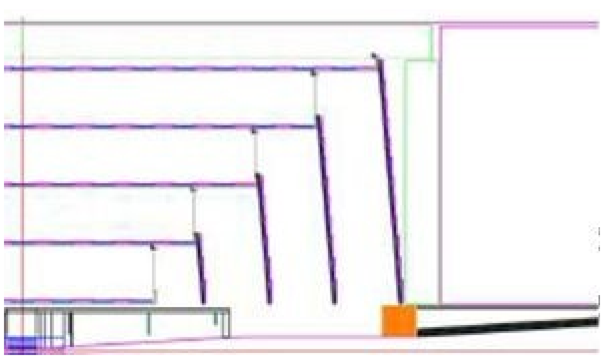
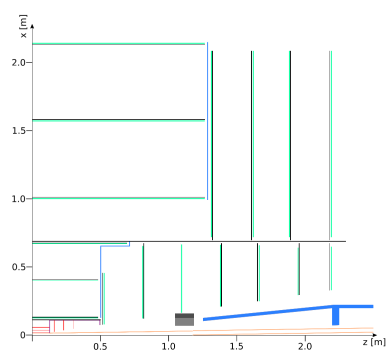


SiD (ILD)



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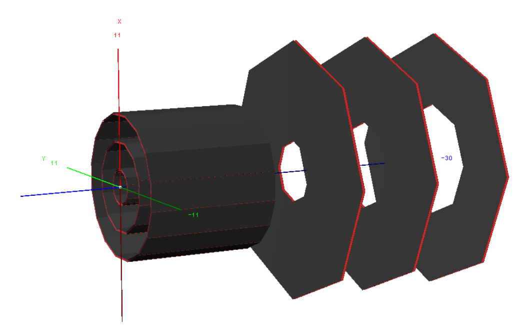

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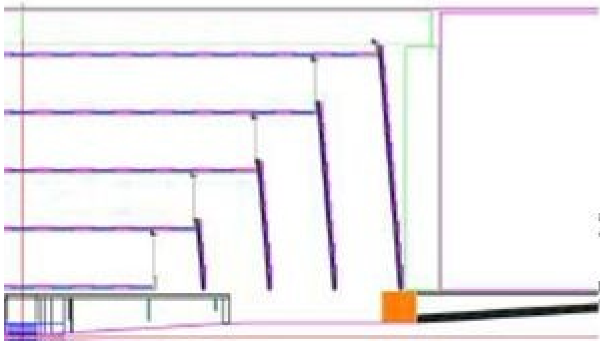

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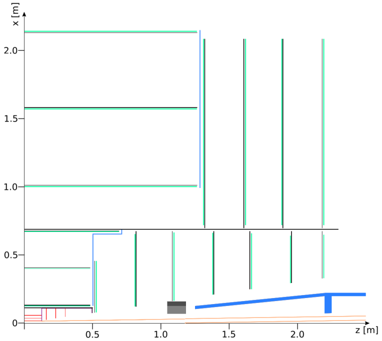

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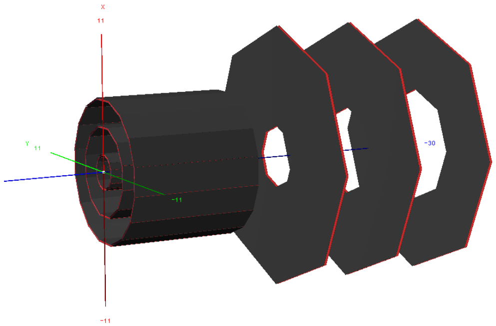

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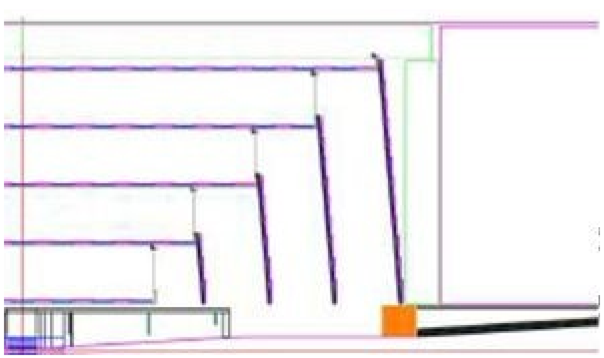

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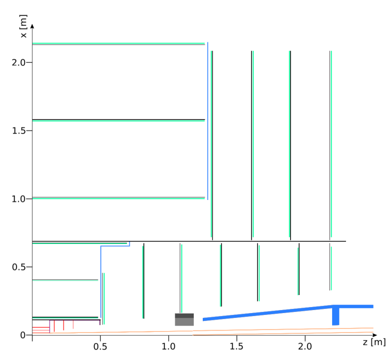

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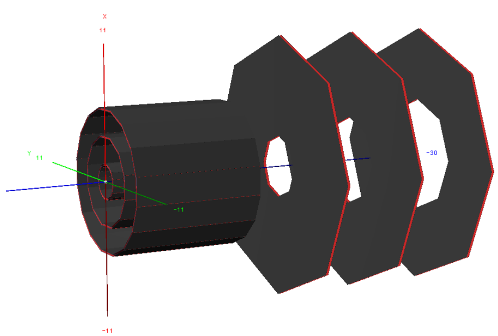

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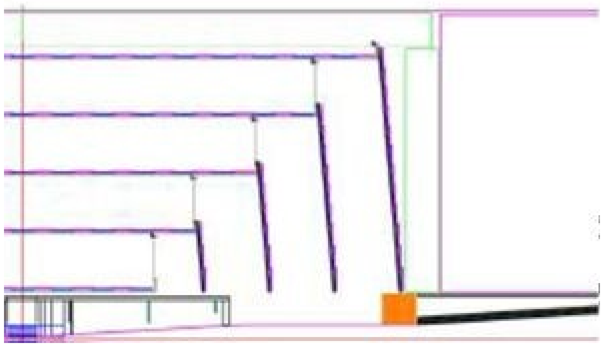
- The maturity of the geometry has paved the way for further developments, such as the ongoing integration of ACTS with the CLD tracking system



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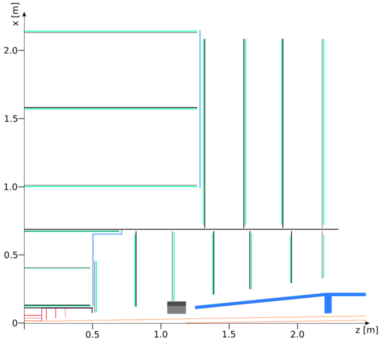

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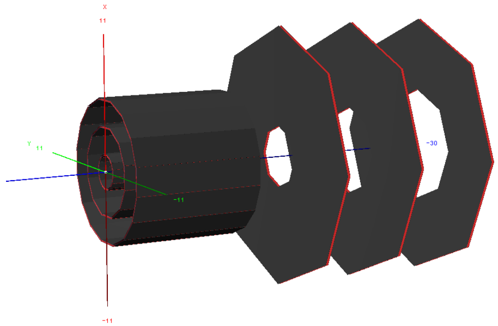
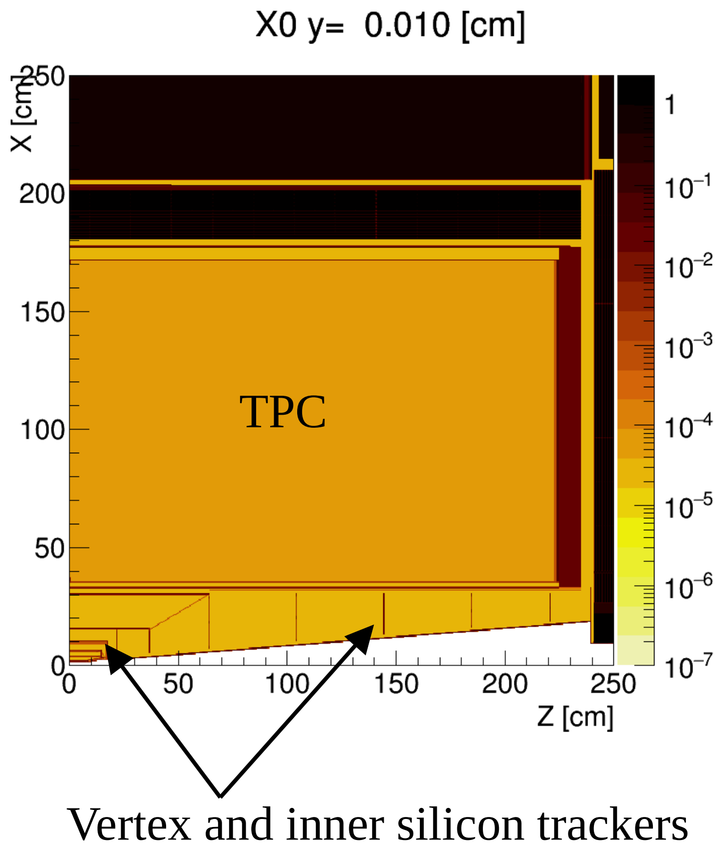


CLD vertex (FCC)

Silicon + gaseous (Time Proj. Chamber) tracking

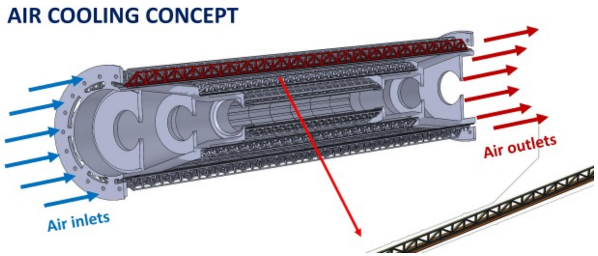
- The tracking system is made up by a silicon vertex and inner tracker, and a TPC as main tracker subsystem
- This combination was developed by ILD (TDR 2013) and adopted by CEPC baseline detector (CDR 2018),
- The geometry of the silicon vertex is more detailed than the one used by full silicon tracking subsystem
- The design of the TPC is an active project supported by the LC-TPC collaboration, and integrated within DRD1 of CERN.
- **A new version of the geometry has been developed for FCC**. See V. Schwan talk [link]. This version is now under study to evaluate the beam-induced backgrounds. See D. Jeans talk [link].



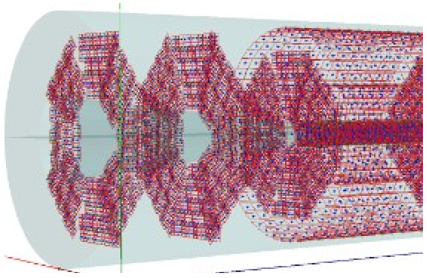
ILD cross section view of the vertex and TPC

Silicon + gaseous (Drift Chamber) tracking

- This combination of silicon vertex and drift chamber is used by IDEA and ALLEGRO (FCC) detectors
- A **newly developed vertex detector driver**
  - Supports both single-sided flat and bent silicon layers
  - **Easy reuse** across different detector configurations.
  - Also used by the Silicon Wrapper subsystem



Vertex support structure



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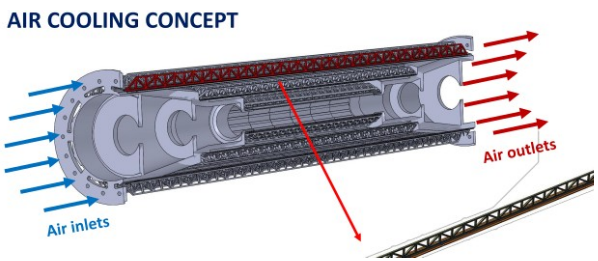
- The stereo drift chamber (DC)
  - **Geometry is fully implemented**
  - Geant4 **physics has to be tuned** and validated against beam test data for acurate simulations. See talk by W. Elmetenawee [link].
  - Preliminary background studies and development of new tracking algorithms are already using this implementation. See D. Garcia talk [link]



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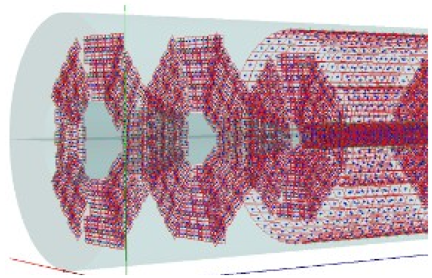

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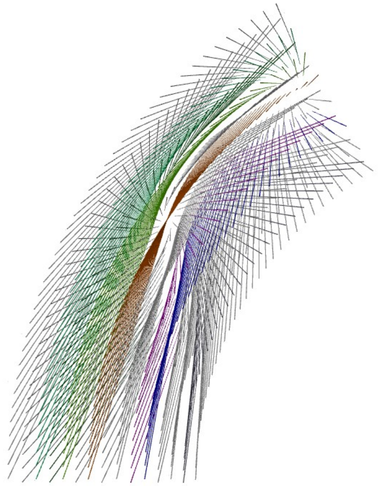

Cross-section of the wires (software)

MEG II, a similar design of a DC

General sampling calorimeter

- Consist in a layered structure covering the barrel and endcap regions.
- The layer structure is given in the compact file
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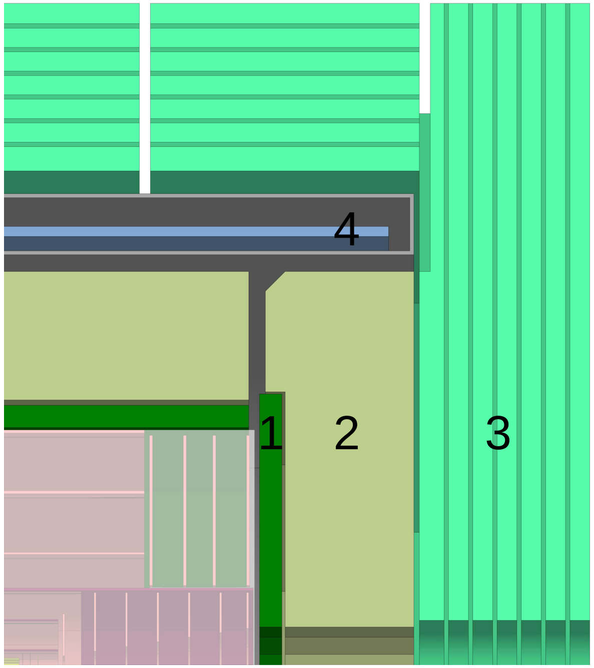
- The same detector driver is used to build the ECAL and HCAL of different detector concepts, including SiD (ILC), CLICdet (CLIC), and CLD (FCC)



CLD outer systems:
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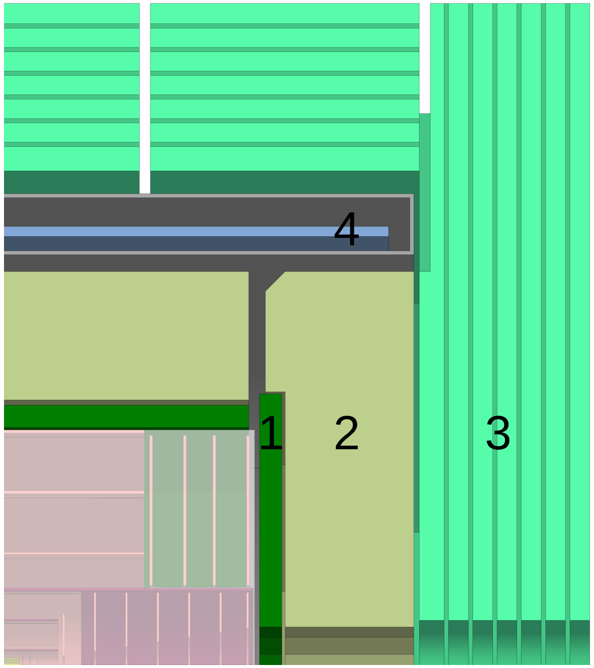

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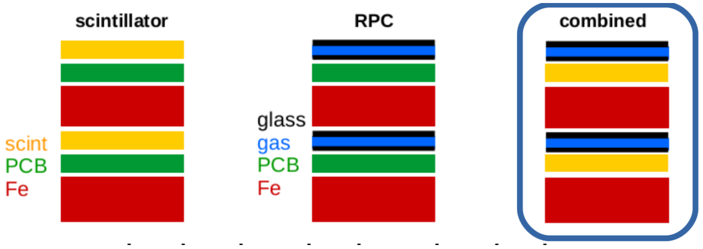

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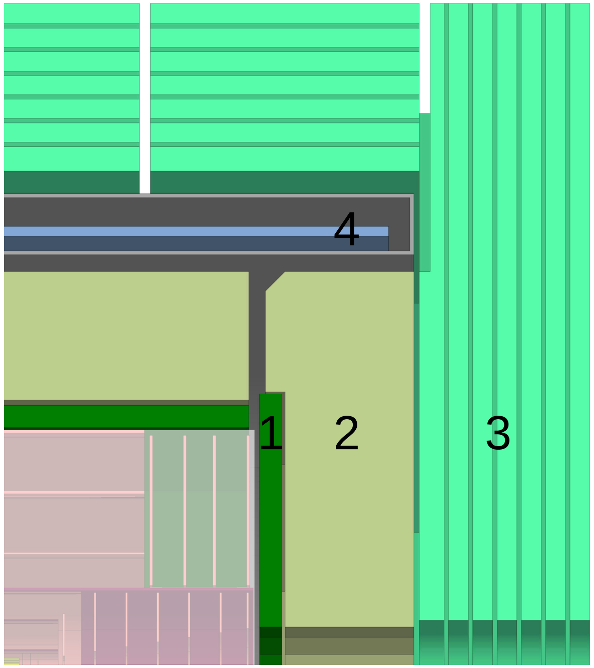
- Baseline detector calorimeters for CEPC are built by specialized detector drivers that follow the aforementioned philosophy



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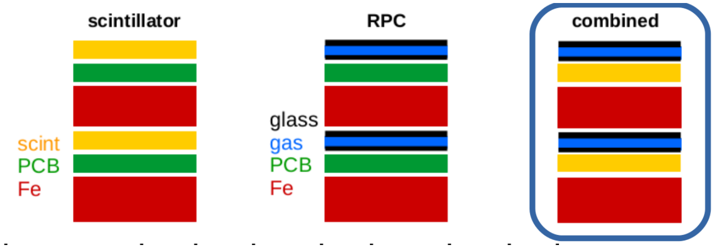
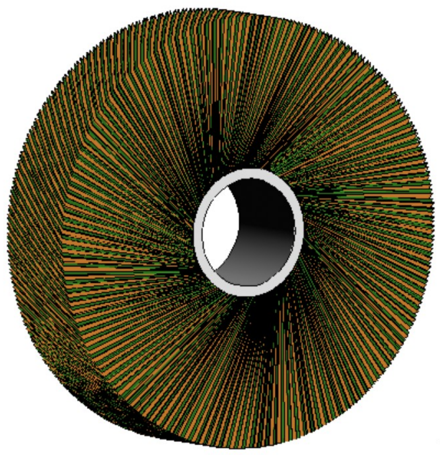


ILD calorimeter

Noble liquid ECAL + TileCal

- These calorimeters used by ALLEGRO (FCC) 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. See F. Sopkova [link] and T. Li [link] talks.
  - First studies using the barrel region in CLD (FCC). See S. Sasikumar talk [link]



Noble liquid ECAL endcap

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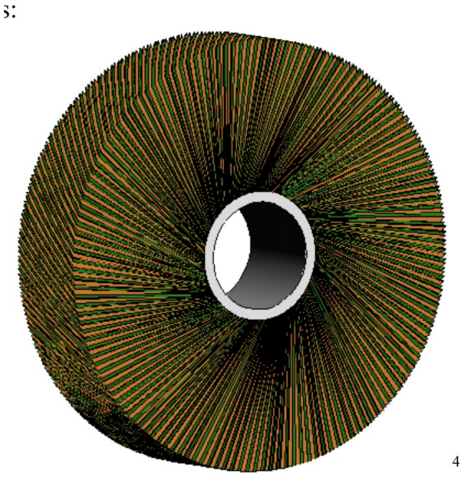
- **TileCal complete detector geometry is also ready.**
  - The segmentation has been updated to be projective in theta, with no significant changes in physics performance.
  - Current developments on optimizing the reconstruction steps.
  - See M. Mlynarikova talk [link]



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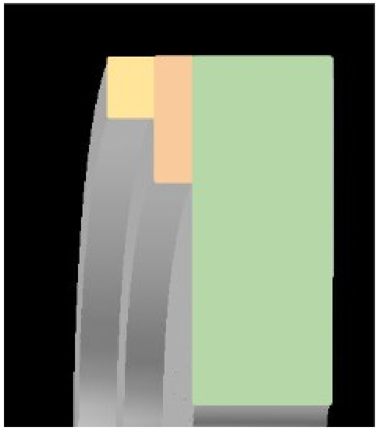

TileCal endcap

Dual-readout calorimeter

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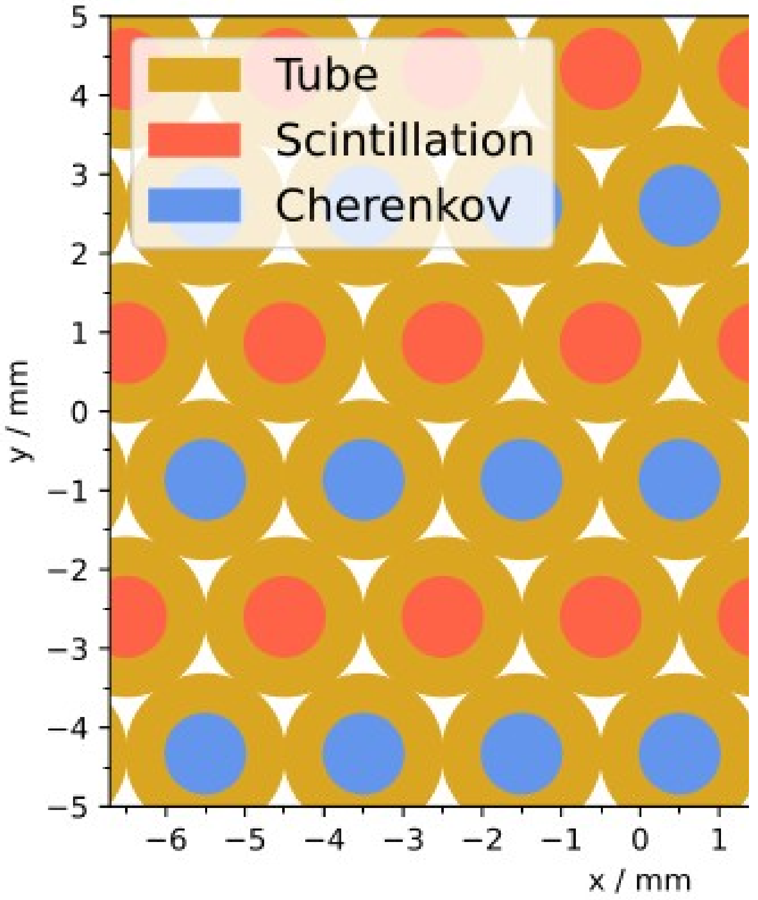
- Two main approaches based on the absorber matrix:
  - In the monolithic option, the matrix fills the spaces between the fibers.
  - In the capillary option, each fiber is placed within a tube, leaving air gaps between the tubes.



Cross-section of the DRC, capilary option [link]

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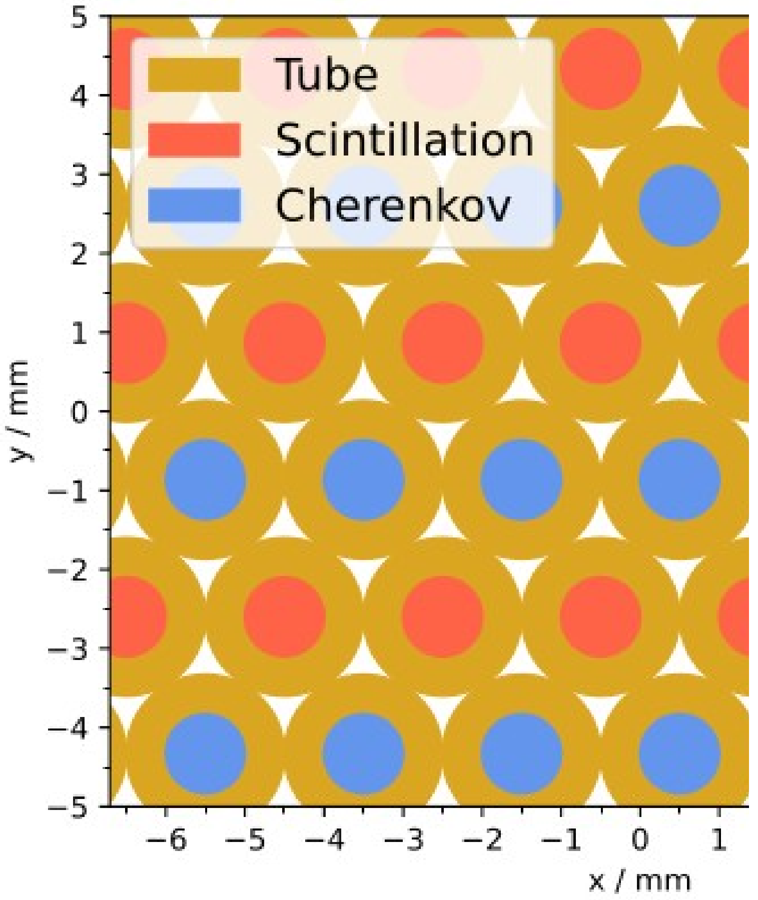
- This is a complex detector concept, **requiring dedicated developments** such as:
  - Custom functionality to record optical photon information
  - A fast simulation for photon transport within the fibers.
- **Detector geometry and Geant4 physics models have been thoroughly validated**, see talk by R. Turra [link].



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Muon systems

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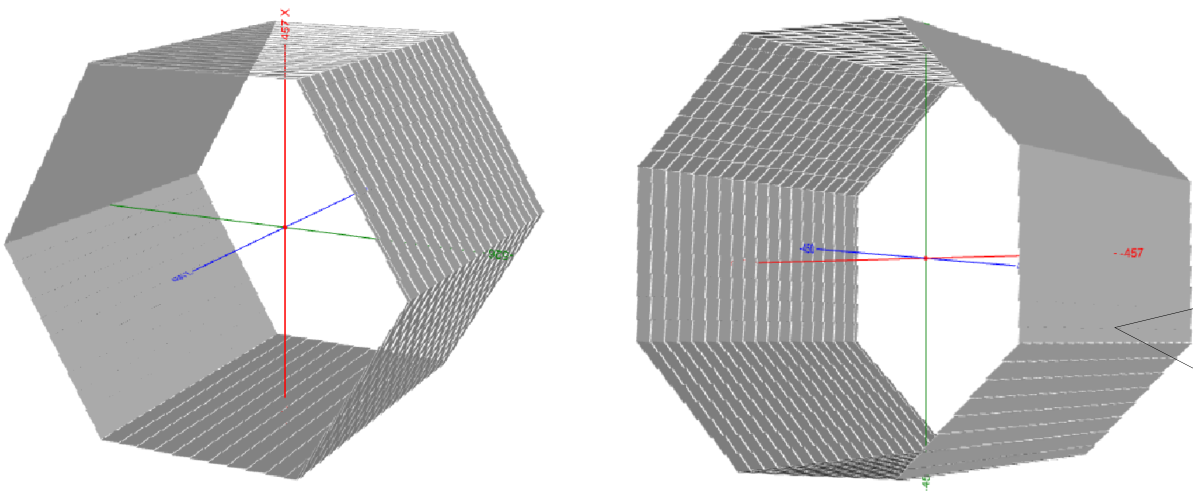
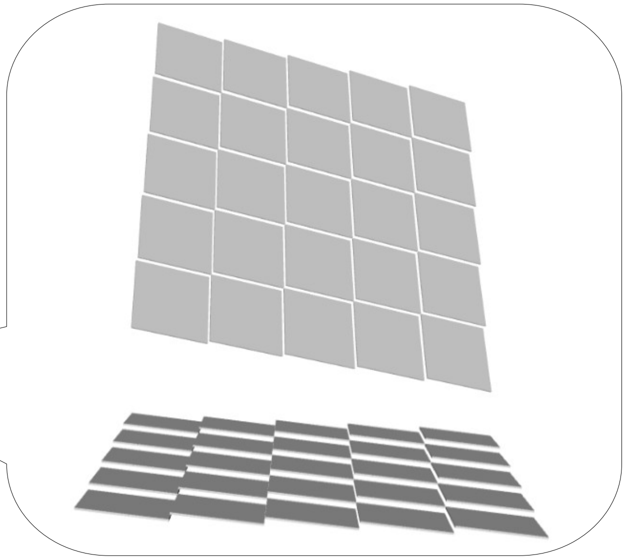
- Detector geometry of the instrumented iron yoke with **Resistive Plate Chambers** (RPC) is built by the same **generic calorimeter detector driver** described before.
- More detailed uRWELL-based systems added recently to k4geo
  - Polygonal geometries easy to tune (number of sides, sizes of the chamber, overlap area for hermeticity)
  - Driver used to build the IDEA muon system and pre-shower detector so far
  - More details in talk by R. Farinelli [link]



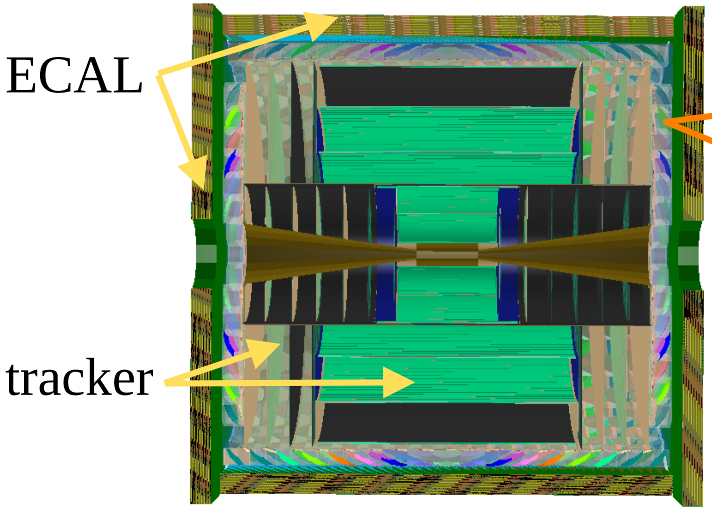
Detailed muon systems, based on uRWELL chambers



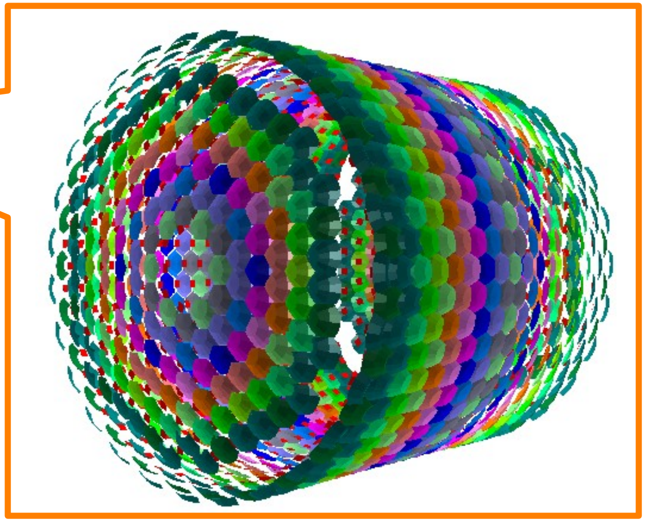
A custom overlap area is achieved by tilting the chambers

PID systems. ARC detector

- The **ARC** consist on an large array of **RICH cells** placed as in the picture below (only mirrors and sensors are visible for simplicity). The detector geometry, material description (including optical properties) and sensor readout is fully implemented in DD4hep
- **New CLD option** with a smaller tracker compared to baseline incorporates the ARC.
  - Tracking performance of this option was presented at LCWS 2024 by G. Sadowski [link].
- First ARC performance studies were presented by S. Pezzulo [link]



CLD with ARC (option 3)



ARC

Summary and outlook

- Many different (sub)detectors are proposed for future colliders (and more to come)
- Delphes simulation in place to easily evaluate performance under different assumptions and set requirements
- Detailed detector geometries are available as part of Key4hep for ILC, CLIC and FCC detectors
- DD4hep-based detector descriptions ensure interoperability thanks to its plug-and-play mechanism, making it easy to create new detector configurations
- Input from detector experts performing beam tests is needed for fine tuning and validation of the physics simulation`