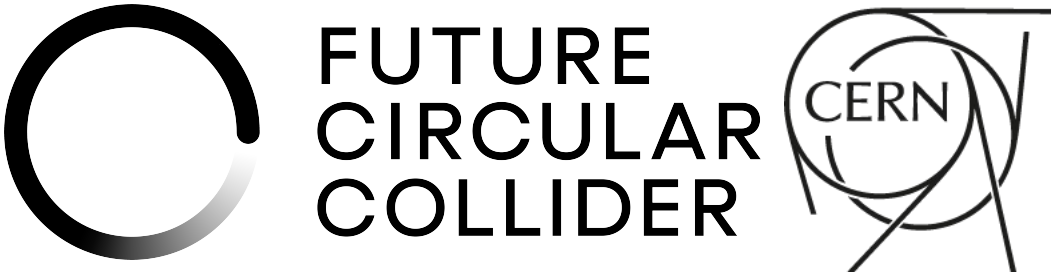
Software for Detector Studies

Status Report

Brieuc Francois (CERN) for the FCCSW team

FCC week 2023, London
Jun. 08th, 2023

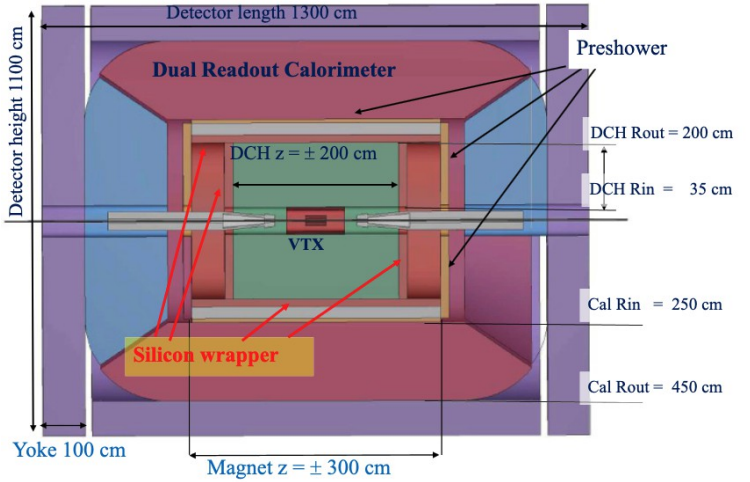


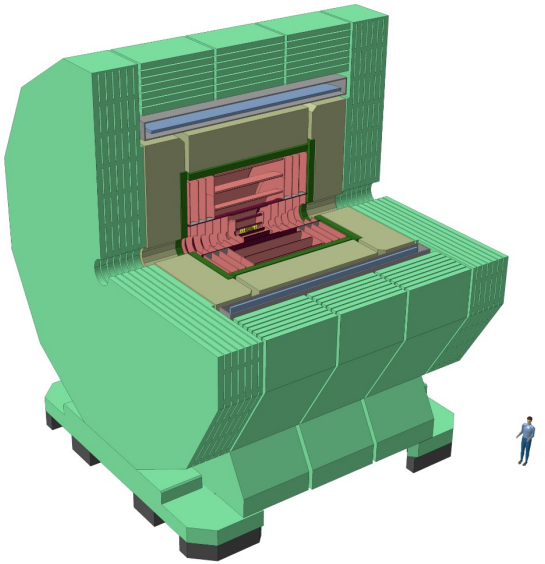
Introduction

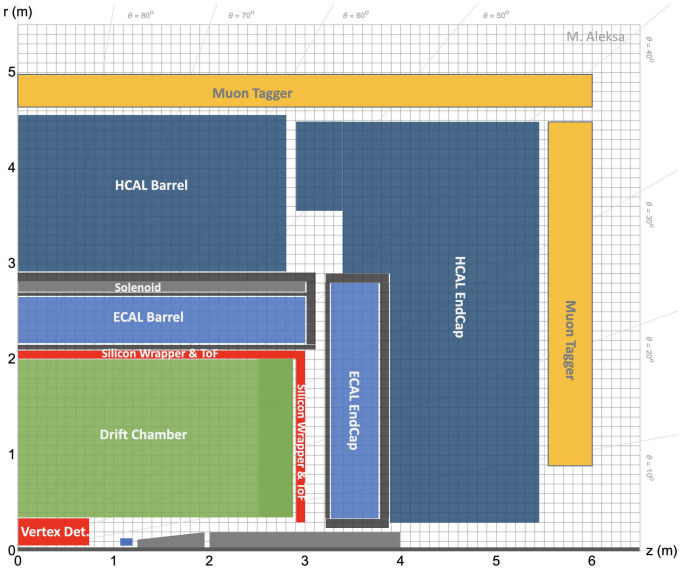
- FCC **feasibility study main deliverables** include
  - **Consolidation of the detector concepts**
    - Optimization of the sub-detectors and of the full detector concepts
    - Demonstration that solutions meeting detector requirements can be realized
    - Convincing arguments will come from detector R&D results and detector full simulation
      - Strong connection between the two communities
      - Full sim is a precious tool to optimize a detector and understand its performance
        - Allows us to evaluate many scenarios and motivate our choices
      - Implementing a sub-detector reliably in full sim requires deep understanding of the important effects at play
- Goal pursued: **all sub-detectors** and their reconstruction **in a consistent framework**
  - To perform full detector concept studies
  - To study various configurations of sub-detectors
    - Swap a technology for another

Outline

- FCC Software General Overview
- FCC-ee Detector Full Sim Readiness
  - IDEA
  - Noble Liquid Based Concept
  - CLD
- Closing Words

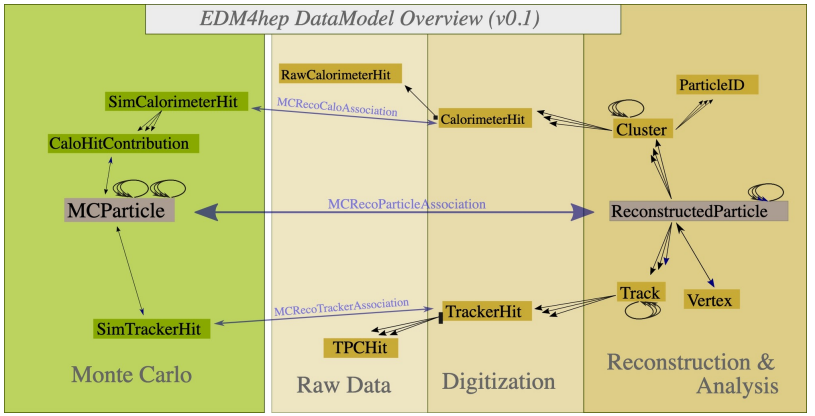


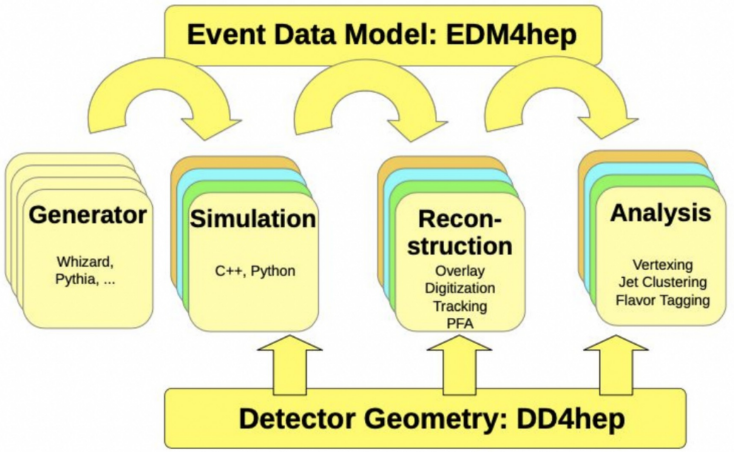




FCC Software Ecosystem in a Nutshell

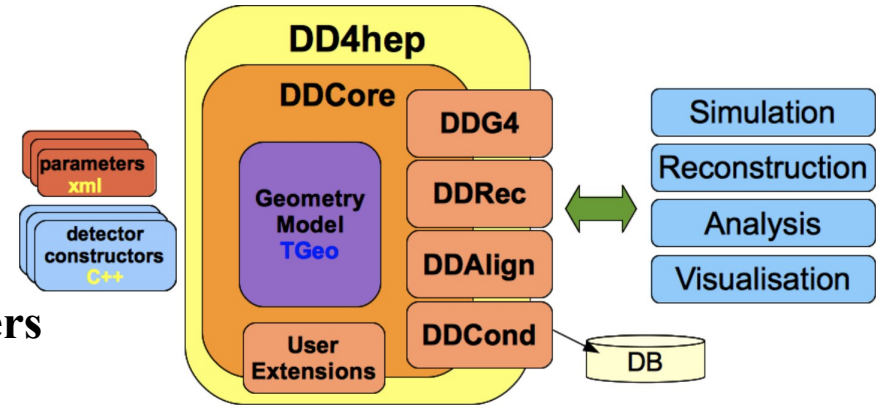
- FCC software fully relies on **Key4hep**
  - Framework meant to **support all future colliders** studies
  - Centrally provides a set of useful HEP packages in a consistent stack
- edm4hep data format, relying on podio
- Well advanced, though not frozen yet: bi-weekly discussion
- Chains of algorithms (Gen, Sim, Digi, Reco) orchestrated with Gaudi
- Detector description based on DD4hep (next slide)



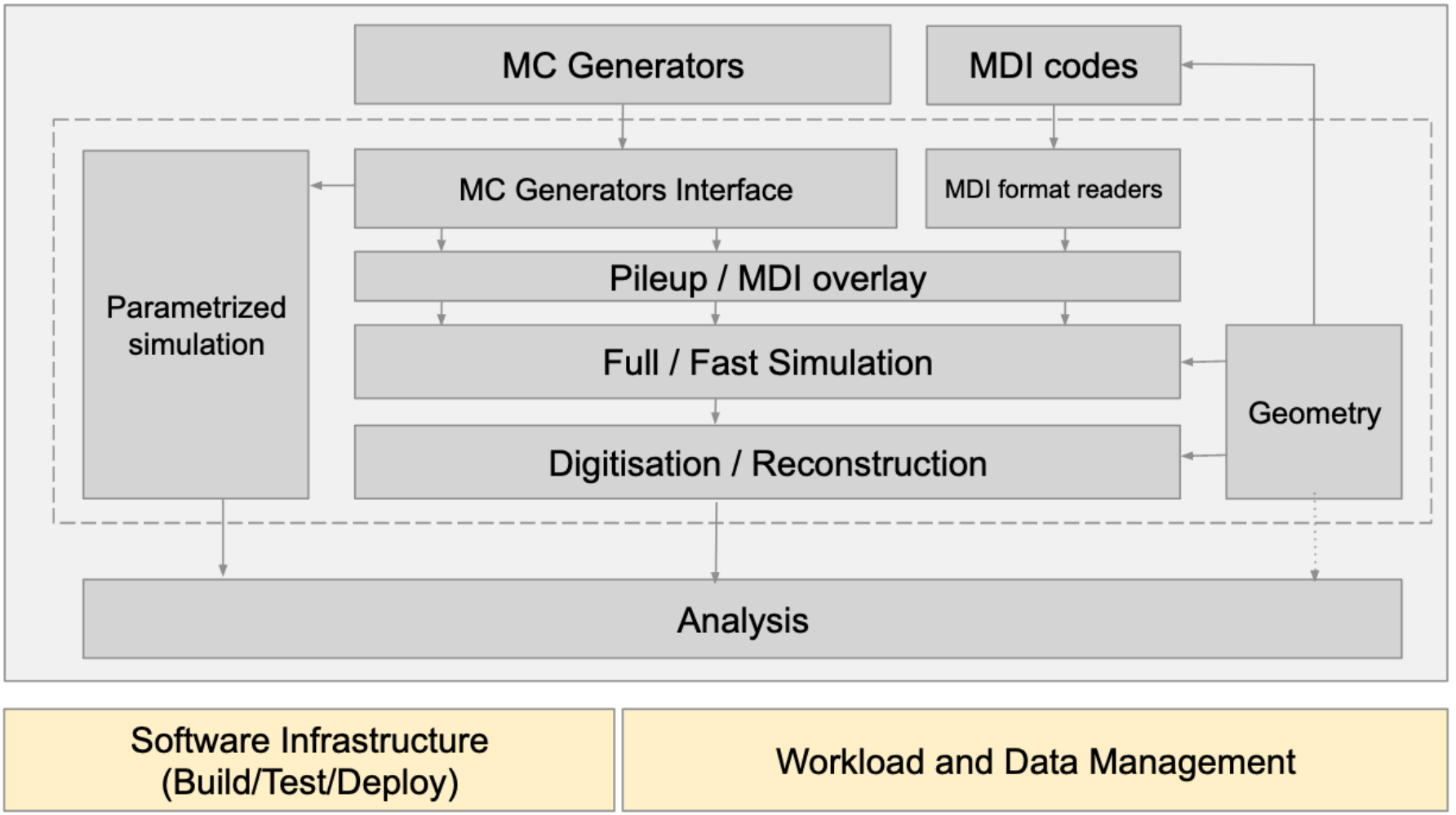


DD4hep

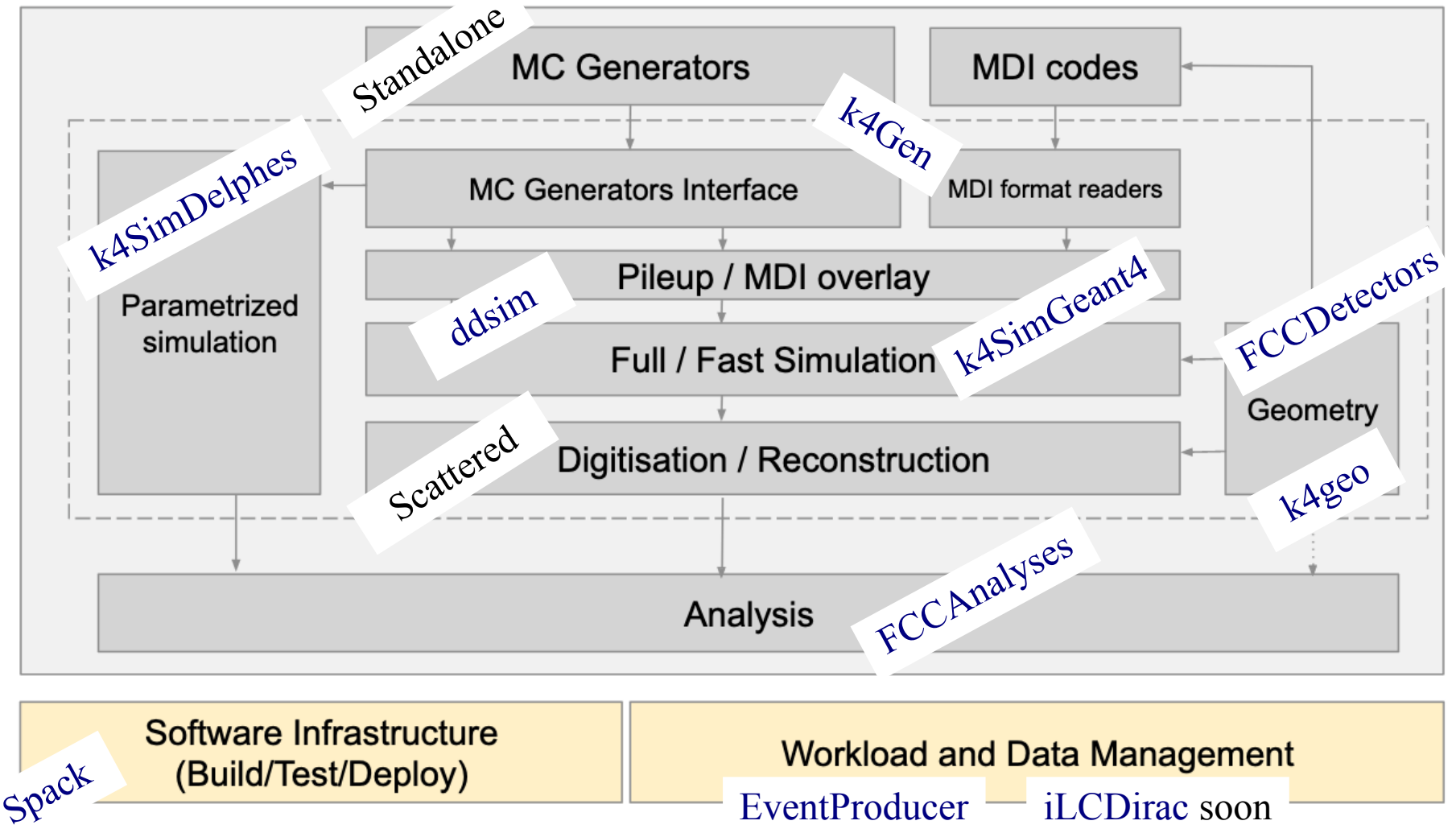
- **DD4hep**: generic detector description framework supporting the full life cycle of experiments
  - Conceptualization, optimization, construction and operations
- Complete description
  - Geometry, material properties, readout, alignment, calibration, …
- DD4hep is **becoming a standard** with strong community support
  - Adopted by CMS, LHCb, ILC, EIC detectors, …
- From the user perspective
  - **C++ for generic geometry structure construction**
  - **XML configuration for detector specific parameters**
  - Can be naively seen as an extra layer **facilitating the interactions with Geant4** and extending it
  - Makes **sub-detector combination much easier**
  - A lot of examples available: link
  - Documentation: User's manual, doxygen



HEP Software Building Blocks



FCC Software Building Blocks



FCC-ee Detector Full Sim Readiness

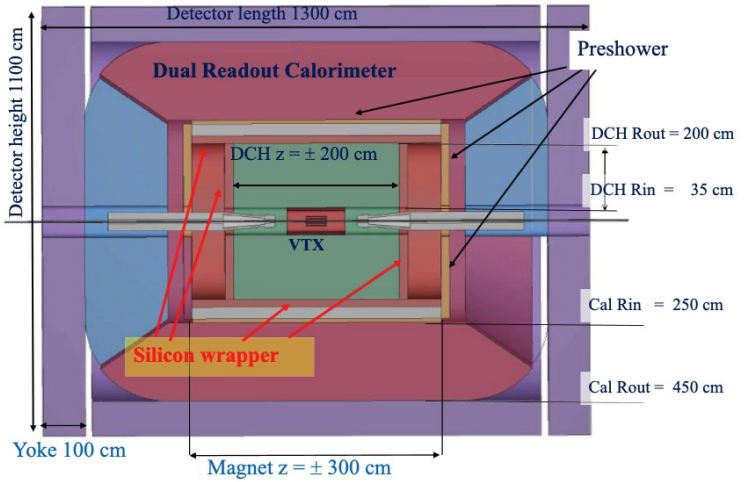
Beam Pipe

Andrea Ciarma

- Beam pipe is common to all detectors
- An updated version is now available in DD4hep
  - Smaller radius: starts at r = 1 cm (instead of 1.5 cm)
- Four components in FCCDetectors under Detector/DetFCCeeCommon/compact/
  - Beampipe, synchortron radiation shields, instrumentation (compensation and screening solenoids), final focusing quadrupole
  - Easy to add/remove component to study e.g. effectiveness of the shields
  - Parts can be made sensitive to study energy deposits (FFquads are supra-conducting)
- LumiCal under Detector/DetFCCeeCommon/compact/LumiCal.xml **Someone?**
  - SiW sandwich layout coming from ILD (few years old)
  - Some inconsistencies spotted w.r.t. current design (thanks Mogens)
    - Should be updated when manpower is found

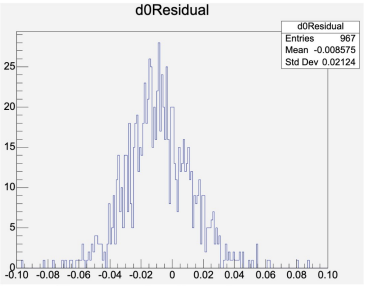
IDEA

- IDEA: Innovative Detector for Electron-positron Accelerator
  - Light vertex detector (DMAPS)
    - Low material budget beneficial for vertex position resolution
  - Light gaseous tracker (2 - 5 % of X_0) + silicon wrapper
    - Large volume needed due to small magnetic field (~2 T, beam emittance)
    - Good PID capabilities thanks to cluster counting
  - Ultra-thin solenoid inside calorimeter
    - Low cost, low material budget needed for particle flow performance
  - Pre-shower and dual readout calorimeter
    - 30 - 40 % / √E jet energy resolution ($H \rightarrow ZZ^{\pi} \rightarrow 4j$ and $H \rightarrow W\,W^{\pi} \rightarrow 4j$ discrimination)
  - μ-RWELL in return yoke
- Alternative option under study: add a dual readout segmented crystal ECAL
  - Greatly improves EM energy resolution and brings some longitudinal segmentation



Vertex Detector in DD4hep

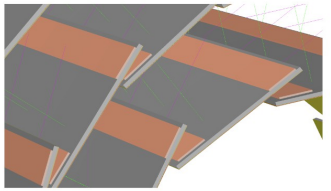
- A new detailed DD4hep description of the Vertex detector is being finalized
  - Simple sensitive plates → accurate material stack of staves, sensors and flex
    - Few overlaps to be fixed
  - WIP pull request already opened PR#273
  - Sim, Digi (simHit position smearing) and Reco available
    - First performance sanity checks performed!
    - ddsim + iLCSoft vertex reco/perf (k4MarlinWrapper)
  - Next steps: add further details (e.g. services), edm4hep native digitization
  - The silicon wrapper will be implemented based on the same detector builders
    - No engineered design available yet
  - More details in Armin's talk!



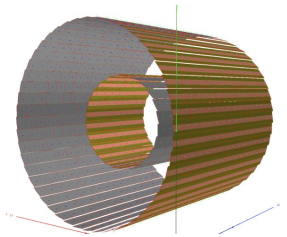
D_0 resolution in mm.

Armin Ilg

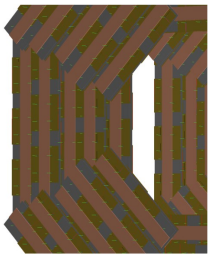
Inner barrel



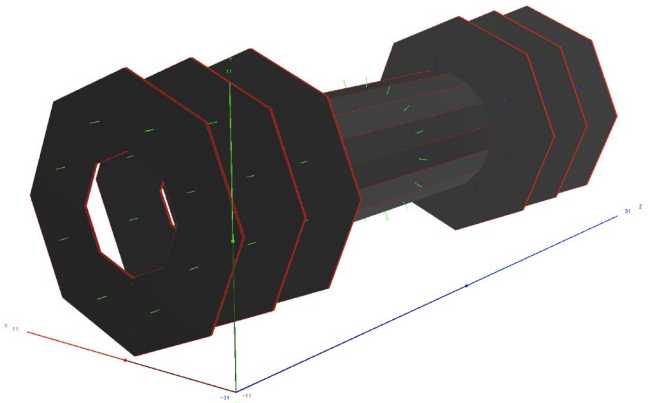
Outer barrel



Endcaps



Previously used version (CLD)

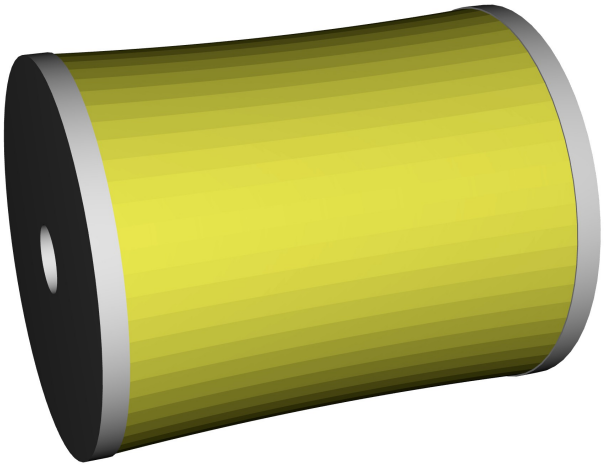


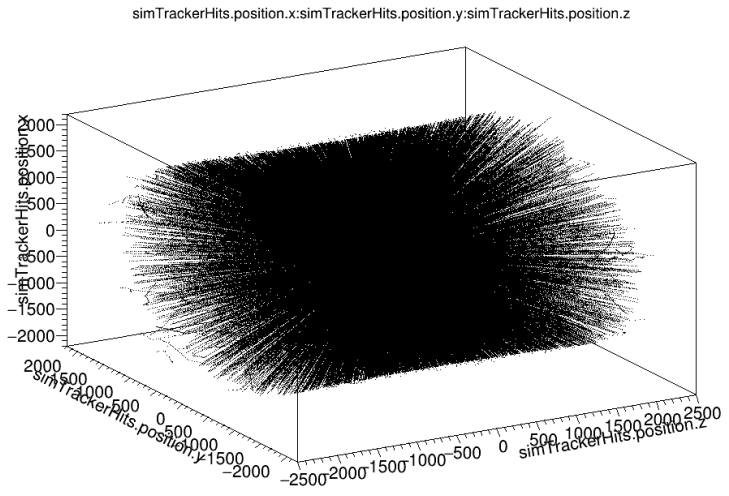
New version

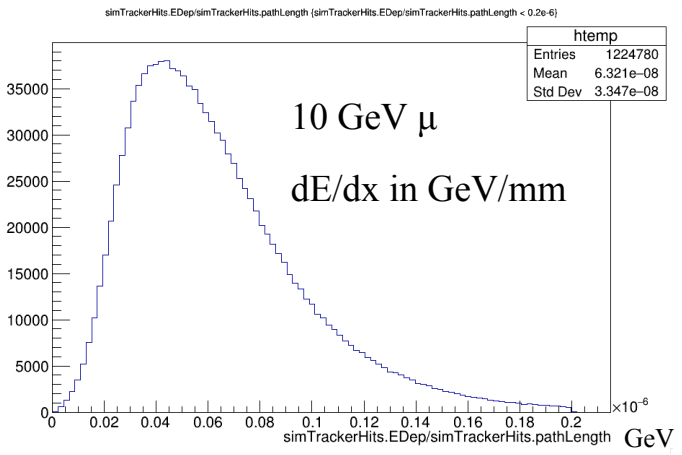
Drift Chamber in DD4hep

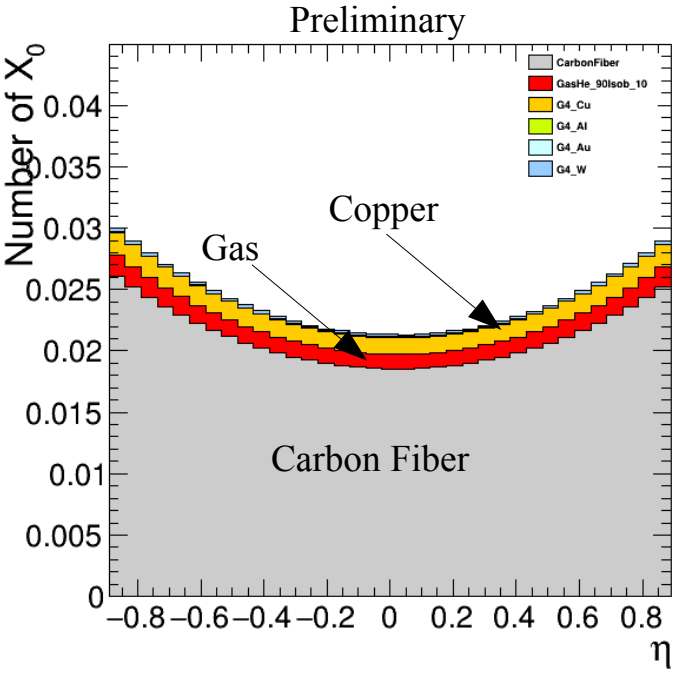
- IDEA DCH originally implemented in plain Geant4: link
- Simplified (no wires) DD4hep version used so far: link
- New detailed **DD4hep implementation available** in FCCDetectors: link (we unfortunately lost the main developer)
  - Carbon fibre/Cu walls, W sense wires, Al field/guard wires, Au coating, includes stereo angle, filled with GasHe_90Isob_10
  - Currently under **debugging and validation**
    - Overlaps to be fixed, material scan, …
  - SimHits can now be extracted! (PR to be opened soon)
    - Comparison with plain Geant4 implementation started
    - Occupancy study can be started once PR is merged

You??



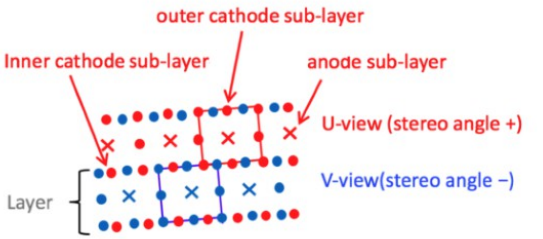




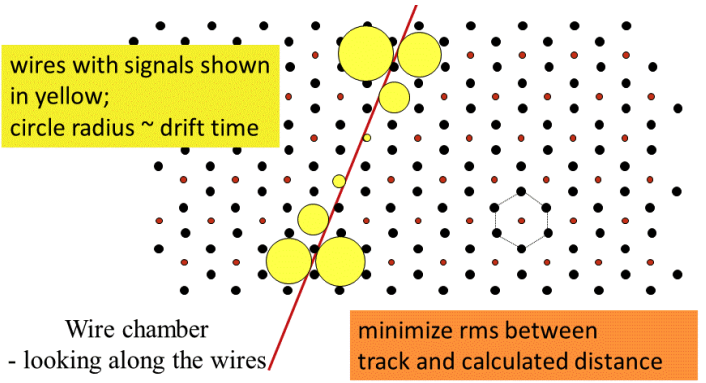


Drift Chamber Reconstruction

- Next step is to implement the DCH reconstruction in Key4hep
  - DCH segmentation into sensitive region (hit ↔ wire)
  - SimHit → RecHit in edm4hep data format, including cluster counting



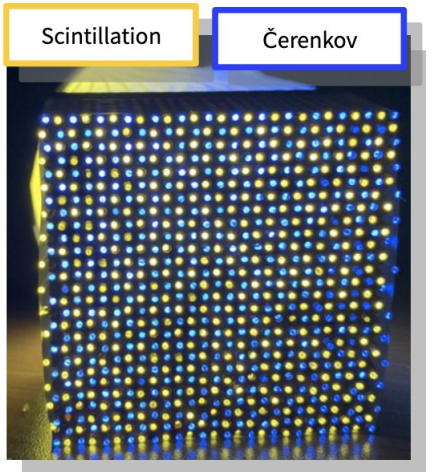
- Prepared k4RecTracker: Key4hep compliant repository to host general VTX and Tracker reconstruction in edm4hep native data format + Tracking
- Tracking
  - Only one algorithm ready to be used in Key4hep: iLCSoft MarlinTracker (CLIC/CLD)
    - Silicon oriented
  - Several solutions could be investigated and wrapped in Gaudi
    - ACTS: needs some data format gymnastic and a way to ship the geometry
      - Solution implemented by EIC
    - ILD approach
      - Track segments built separately in inner Si-tracking and TPC, then combined
    - BES III solution: TrackNETv2 (machine learning based)
    - Genfit: already available as a Key4hep package, only for track fitting
  - Implement our own Key4hep native drift chamber tracking algorithm?

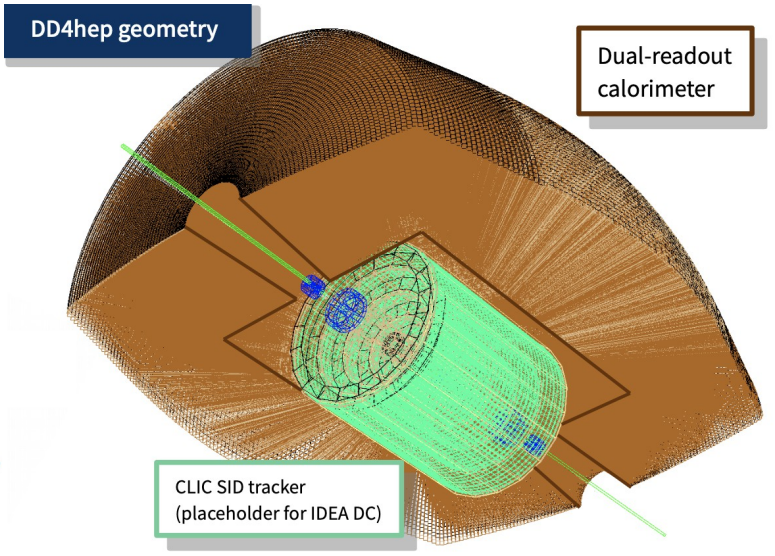


Dual Readout Fiber Calorimeter

Sanghyun Ko

- Dual readout calorimeter fully available in Key4hep: HEP-FCC/dual-readout
  - Geometry, simulation, digitization, reconstruction
  - Custom segmentation (more fibers in the rear than in the front)
  - Optical physics included: link
    - Fast Sim module applied to optical photons: link
  - SiPM emulation with external package: SimSiPM
- Next steps
  - Integrate geometry in the central repository (k4geo)
  - Further work on lowering CPU cost of simulation
  - More details in Sanghyun's talk!





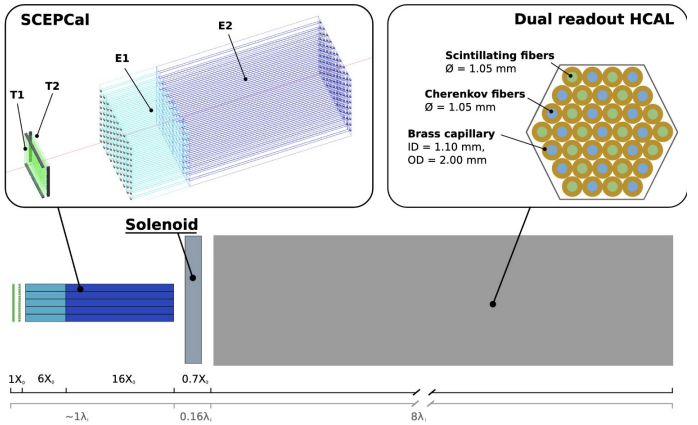
K4SimGeant4 configuration

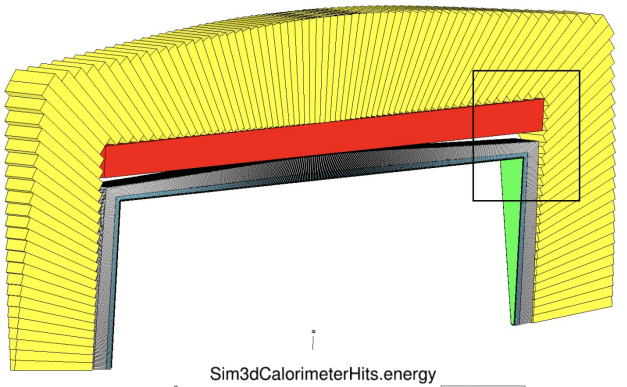
```
regionTool = SimG4FastSimOpFiberRegion("fastfiber")
opticalPhysicsTool = SimG4OpticalPhysicsList("opticalPhysics", fullphysics="SimG4FtfpBert")
physicslistTool = SimG4FastSimPhysicsList("Physics", fullphysics=opticalPhysicsTool)

from Configurables import SimG4DRcaloActions
actionTool = SimG4DRcaloActions("SimG4DRcaloActions")

# Name of the tool in GAUDI is "XX/YY" where XX is the tool class name and YY is the given name
geantservice = SimG4Svc("SimG4Svc",
  physicslist = physicslistTool,
  regions = ["SimG4FastSimOpFiberRegion/fastfiber"],
  actions = actionTool
)
```

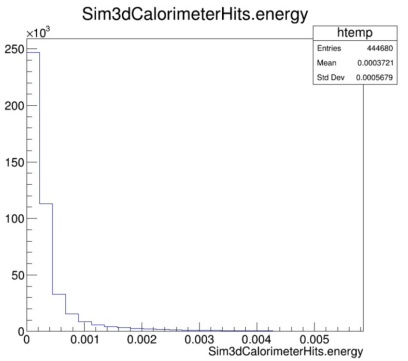
Dual Readout Crystals in Key4hep

Wonyong Chung and Marco Lucchini

- Alternative detector configuration with greatly improved **EM energy resolution/longitudinal segmentation** under study
  - Add longitudinally segmented **dual readout crystals** in front of the HCAL (before the solenoid)
  - Again, has to be integrated in the common framework to study this alternative detector concept
- Detector description implemented in DD4hep: link
  - Great synergies with fiber dual readout!
    - Used the same Github repository as starting point
  - SimHits available
- WIP: port the code to the central dual-readout repository, digitization, reconstruction, Particle Flow (not Pandora based)

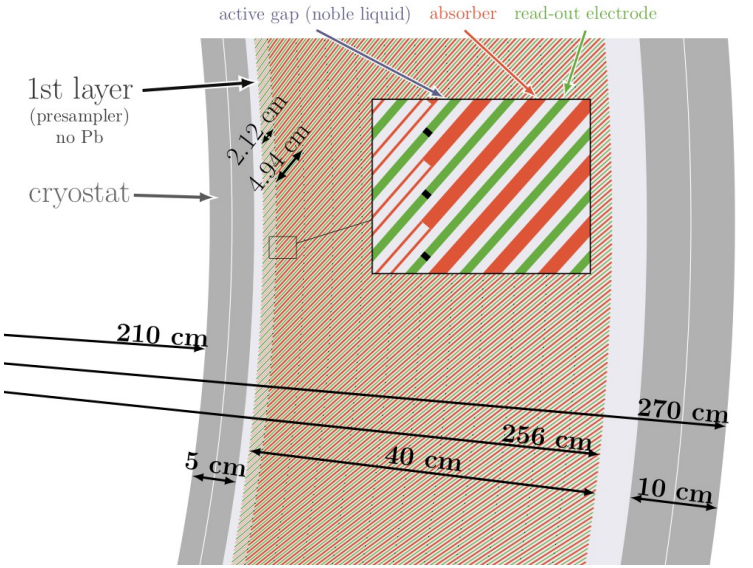


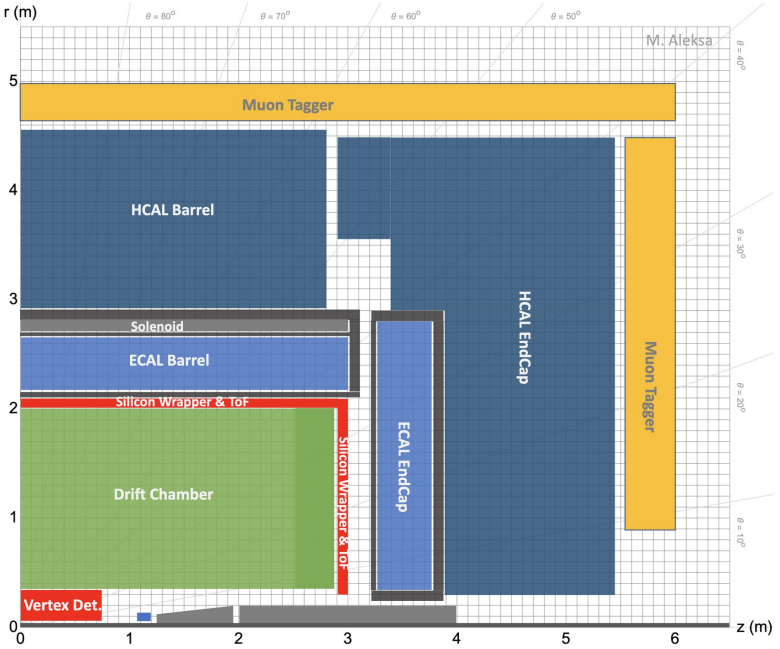




Noble Liquid Based Concept

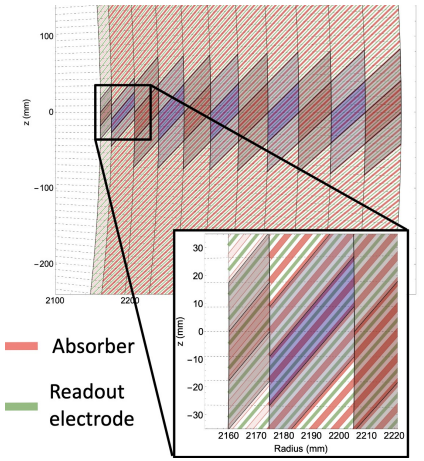
- Noble Liquid based concept (will soon have a real name!)
  - New detector concept w.r.t. CDR
  - Started with a high granularity noble liquid ECAL
    - Pb/W inclined absorbers, LAr/LKr sensitive media, highly granular readout electrodes as multilayer PCB
  - Now dressing it with other sud-detectors
  - Current plans
    - Drift chamber and vertex detector similar to IDEA
    - Coil after ECAL inside the same cryostat
    - Scintillator based HCAL (acting as a return yoke)
    - Muon system TBD

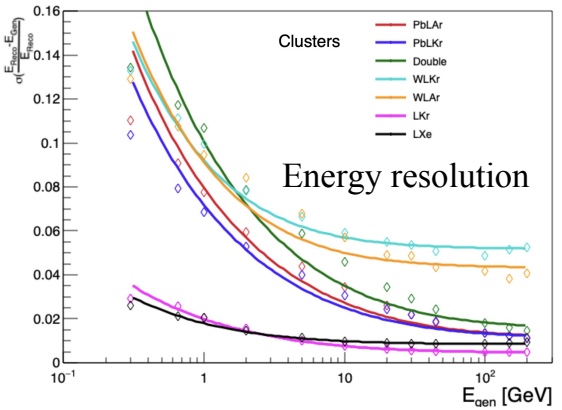


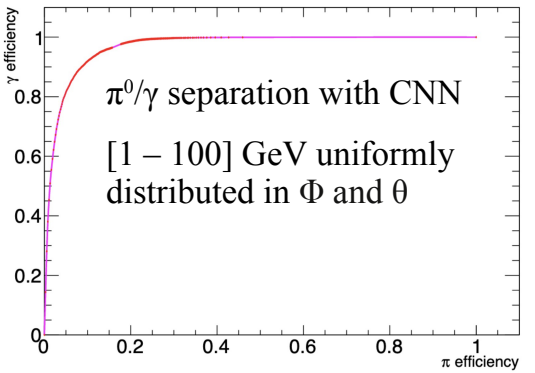


Noble Liquid Based Concept in Key4hep

- Current detector description in DD4hep: link
  - Simplified vertex (CLD), will be updated to the detailed IDEA one
  - Simplified drift chamber (no tracking available)
  - **ECAL Barrel fully available in Key4hep**
    - Inclined absorber plates that can be made trapezoidal
    - Cryostat, services and solenoid material budget included
    - **Calibration, noise and clusterings available** as edm4hep native Gaudi algorithms!
    - **Plug-and-play compliant**
      - Good factorization between xml and cpp builders
      - Automatic rescaling upon geometry changes
    - **First performance studies performed**
    - Need **Particle Flow** to optimize granularity, requires tracks
      - Prepared a detector configuration with CLD + LAr ECAL
        - Temporary hack to exercise the technical machinery
      - Working now on PandoraPFA integration
  - ECAL endcaps under validation

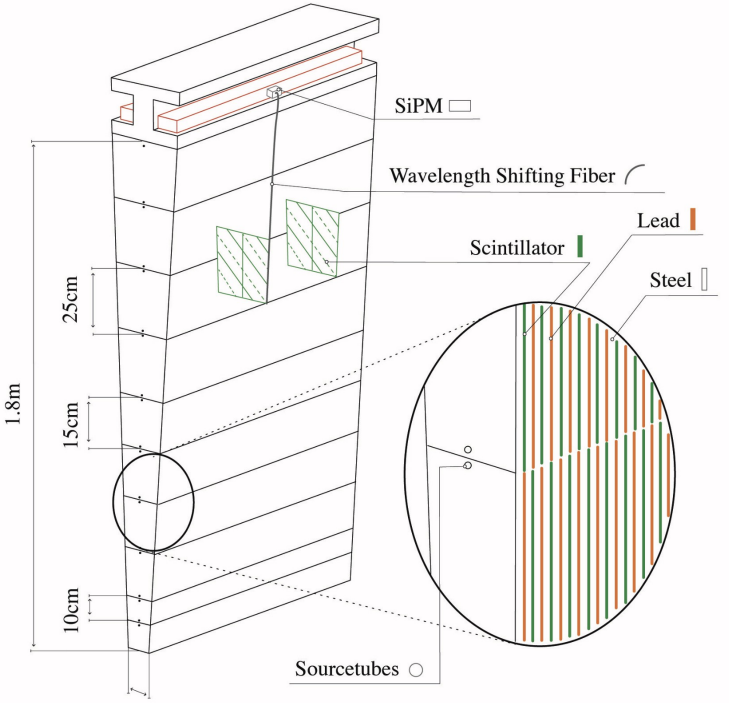


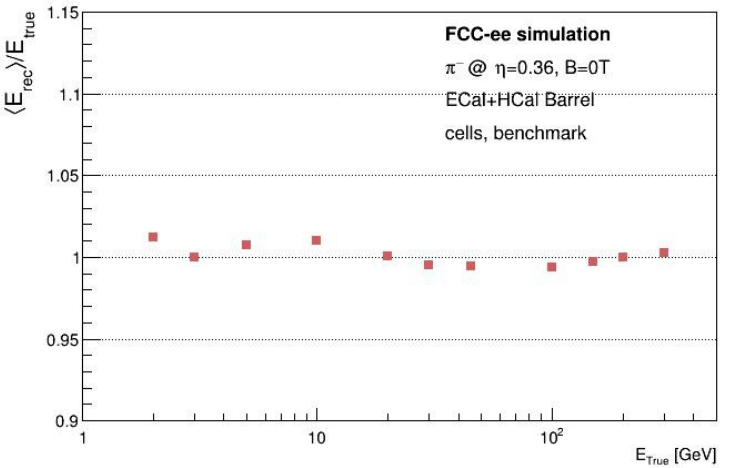




Noble Liquid Based Concept in Key4hep

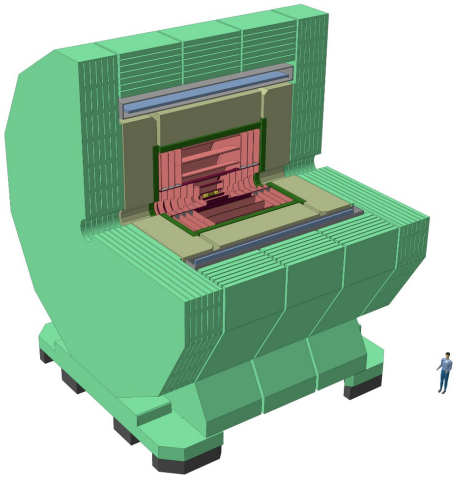
- HCAL geometry implemented in DD4hep: link
  - Sim, Digi, Reco available
  - Clustering (need to bridge ECAL and HCAL)
    - Sliding window ready
    - Topological clustering needs some fixes
    - Calibration as edm4hep native Gaudi algorithm
      - Benchmark analytical method available
      - Machine learning based will be investigated
    - First performance studies started
      - Nice linearity
  - More details in Michaela's talk!
- Muon chambers as simple sensitive plates for now



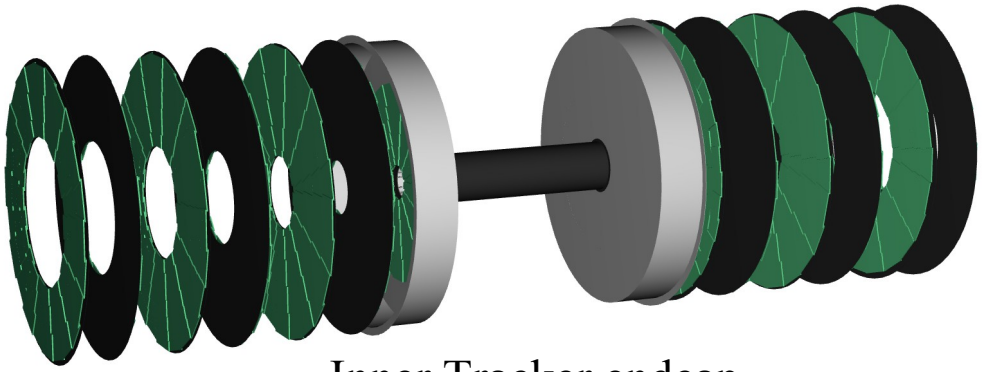


CLD in DD4hep

- CLD (CLIC-like detector)
  - Full silicon vertex + tracker
  - Highly granular SiW ECAL + scintillator-steel HCAL
  - Superconducting solenoid outside HCAL
  - Steel yoke with RPC's



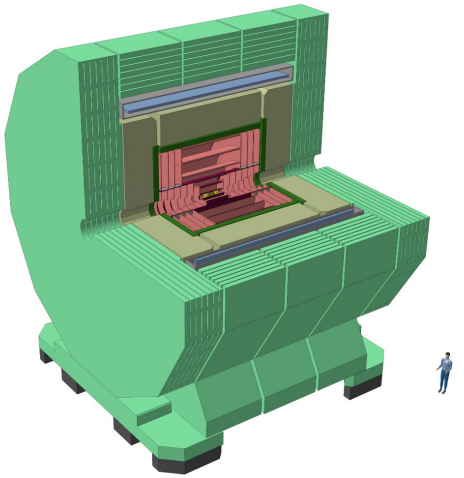
- **All CLD sub-detectors implemented in DD4hep!**
  - Several configurations envisaged
  - Link to geometries
  - Last update: added tracker support structure
    - Some overlaps to be fixed
  - Possible improvement towards plug-and-play
    - Further automatize global parameter modifications
      - E.g. changing tracker outer radius requires manual interventions



Inner Tracker endcap

CLD Full Sim Status

- Full simulation + reconstruction workflow available!
  - Simulation through *ddsim*
  - Reconstruction through *Marlin*
    - Background overlay, digitization, conformalTracking, ParticleFlow (PandoraPFA), vertexing and flavor tagging
    - Inherited from ILD/CLICdet
- *Marlin* reconstruction based on LCIO data format but can be **integrated in EDM4hep Gaudi based workflows** through the *MarlinWrappers* + data format translation
  - Example of steering file
- Improvement towards inter-operability
  - Be able to run Marlin Reco after having simulated CLD with k4SimGeant4
    - Differences in the way Geant4 hits are stored (modifs could be applied to k4SimGeant4)

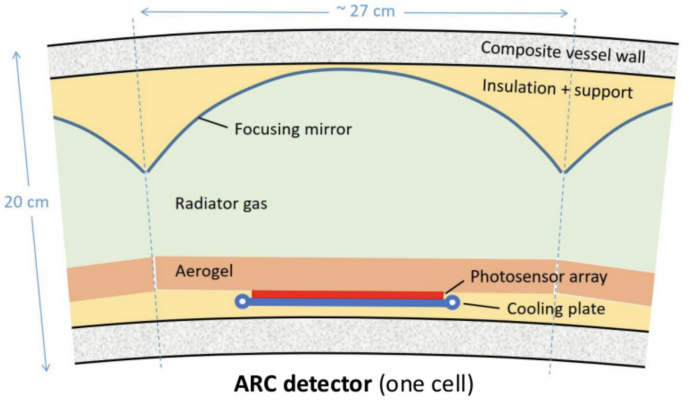


```
ddsim --compactFile FCCee_o1_v05/FCCee_o1_v05.xml \
      --enableGun \
      --gun.distribution uniform \
      --gun.energy "10*GeV" \
      --gun.particle mu- \
      --numberOfEvents 100 \
      --outputFile Step2_edm4hep.root
```

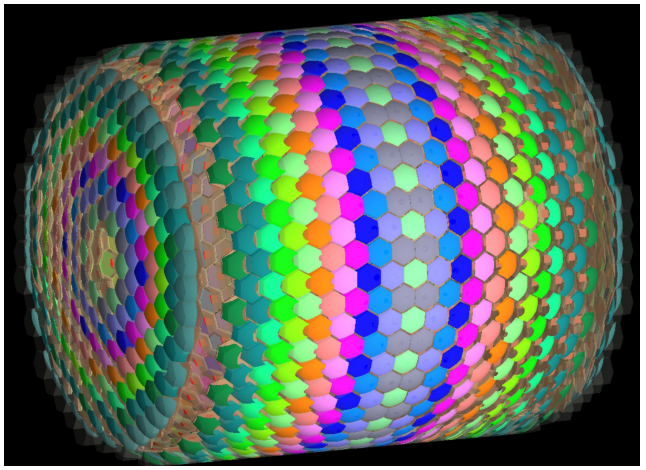
Link to tutorial

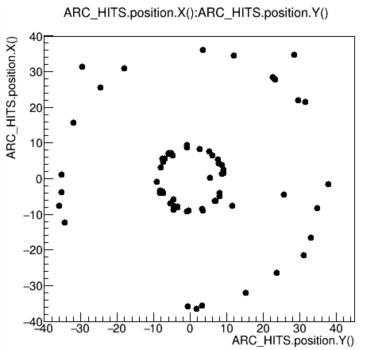
ARC

- Dedicated Particle Identification (PID) detector could greatly improve PID capabilities (flavor, Higgs)
  - Currently implementing the ARC (Array of RICH Cells) detector in Key4hep
    - Barrel and endcap geometries ready (PR#271 in k4geo)
      - SimHits available (ddsim so far)
    - Working now on digitization and reconstruction
      - Hosted in k4RecTracker for now (similar to VTX)
  - Improvement towards plug-and-play
    - Most detector dimensions currently hard-coded
    - All free parameters (e.g. mirror position and orientation) have to be carefully re-optimized upon e.g. radial position change
      - Current optimization strategy not easy to integrate
- Will prepare a CLD version including ARC (PID needs track)
  - Allows us to evaluate performance in a global environment
- Much more details will be provided in Alvaro's talk

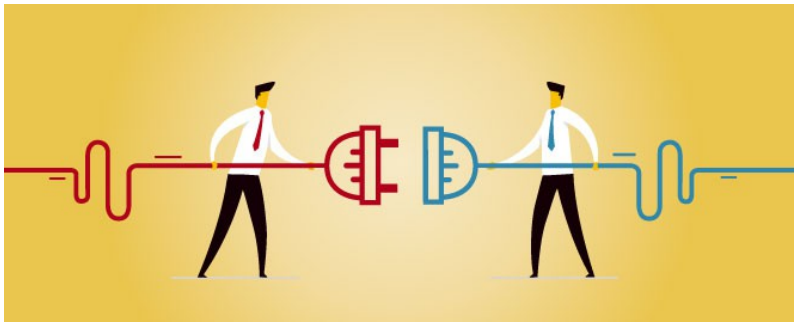


ARC detector (one cell)





Inter-operability



- "Only" three detector concepts at the moment
  - Already **a lot of sub-detectors** to model and more are to come!
- All concepts are still evolving → need flexibility and inter-operability
  - Want to be able to easily **study** many **different detector concept configurations**
    - Sub-detector content, extent, position, …
  - **Plug-and-play** approach made **possible** by DD4hep **but not granted**
    - Some ingenuity required in designing the C++/xml architecture
  - A common data format is not enough, needs additional prescriptions
    - Strategy to store Geant4 hits, fields with freedom left to the user (e.g. calo clusters shape parameters), …
- FCC detector geometries are being moved from FCCDetectors to k4geo
  - Linear collider detectors already hosted there
  - Having all sub-detector geometries in a common place will ease inter-operability, grid submission
  - This repository could also host test-beam module description
    - A flexible enough detector builder (C++) should allow us to easily write the xml for a small module

Organizing the Effort

- Building now a **collaboration** of people working on FCC detector **Full Sim in Key4hep**
- Starting a **bi-weekly working meeting on FCC Detector Full Sim: indico page**
  - Mondays at 11 am CEST
    - Flexible on the frequency and time (will sometimes move to an afternoon slot for people on the other side of the Atlantic)
  - Subscribe to the **FCC-PED-SoftwareAndComputing-Full-Simulation** CERN e-group to receive the announcements
  - Scope: detector **implementation**, **simulation**, **digitization**, **reconstruction** and **performance**
    - **Working meeting**: issues faced, lesson learned, status report, questions, unpolished plots, …
  - Will try to **integrate also the detector physics community**
    - Deep detector expertise needed to write their full sim
    - Upstream detector design updated from R&D teams to the simulation
- **More contributors needed!**
  - Full Sim is a complex business, long ramping-up phase, requires **good software skills** and uninterrupted commitment
    - Better to have 1 person at 50-100% than 5 people at 20%
  - Expertise should be maintained on the **long run**
    - Writing digitization and reconstruction requires to know how the detector was implemented

Summary

- Many IDEA sub-detectors start being available in DD4hep/Key4hep
  - Various stages of development (Sim, Digi, Reco) and validation
    - Missing the pre-shower and muon chambers (4 months intern starting in August)
  - Would benefit from more **dedicated manpower,** especially for the drift chamber
- Noble Liquid based concept has ECAL and HCAL, muon chambers as sensitive plate
  - Will use IDEA drift chamber and vertex detector when ready
  - The team is growing!
- All baseline CLD detectors implemented in DD4hep
  - Sim, Digi, Reco available through Marlin with data format translation
    - Does not mean that we are done! (further optimization, maintenance, inter-operability, …)
  - Adding an option with ARC PID detector (SimHits available, reco ongoing)
  - Very active in the past (ILD/CLIC), need to revive the effort!
- All detector description being migrated to a common repository
  - Inter-operability, user-friendliness, grid submission
- FCC Detector Full Sim Working Meeting being started
  - Build a collaboration of people working on Full Sim
    - Need long term commitment and teams to carry the expertise on along the way
  - Bring together software and detector expertise