CLD detector model overview of layout and performances

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CLD - detector model for FCC-ee derived from CLICdet model and optimized for FCC-ee experimental conditions

CLIC

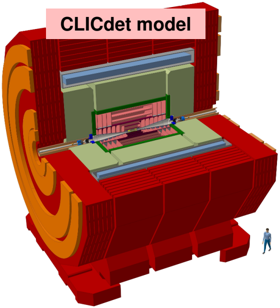
- Compact Linear Collider ($e^- e^+$)
- 3 energy stages:
  380 GeV, 1.5 TeV, 3 TeV
- 156 ns long bunch trains;
  20 ms distance between trains
  $\rightarrow$ Power Pulsing of electronics
  $\rightarrow$ Air cooling of Vertex detector
- CLICdet - proposed detector for CLIC

FCC-ee

- Future Circular Collider ($e^- e^+$)
- 4 energy stages: 91 - 365 GeV
  $\rightarrow$ thinner calorimeter is sufficient
- Bunch spacing: 20 - 3396 ns

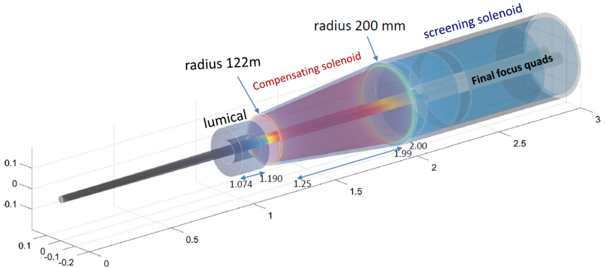
Both experiments demand state-of-the-art detectors with:

- low-material tracking system
- precise calorimetery



Detector constraints from the FCC-ee machine design

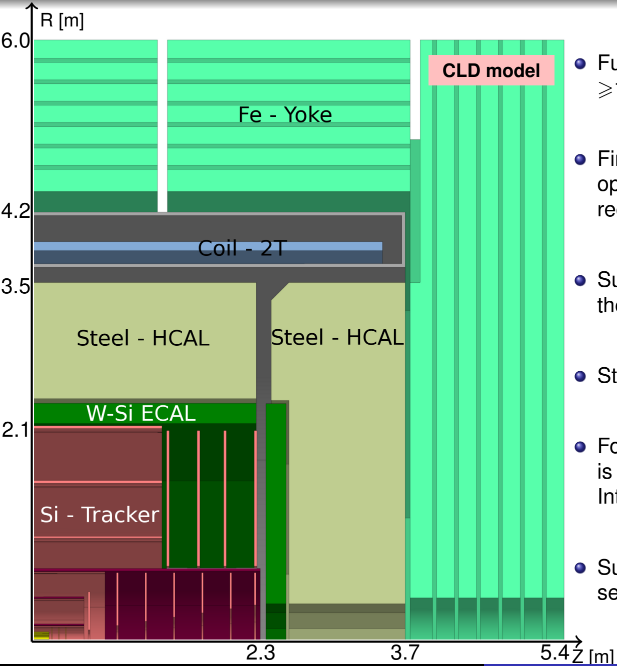
- In order to maximize luminosity final focusing quadrupole chosen to be at 2.2 m from IP - **inside the detector**
- Compensating solenoid to prevent emittance blow-up from detector magnetic field due to non-zero crossing angle is even closer to the IP
  $\rightarrow$ **forward region within 150 mrad is reserved for Machine-Detector Interface**
- Constrains **the maximum possible detector magnetic field to 2T** (while the CLIC proposal assumes 4T magnetic field)



CLD detector layout

- ✳Tracking system
- ✳Calorimetry
- ✳The magnet and muon system

CLD detector layout



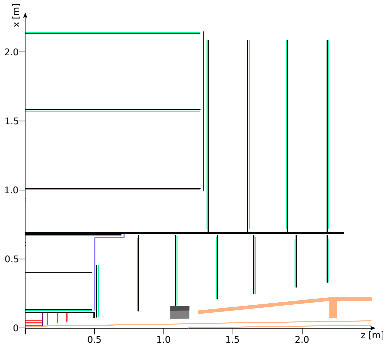
- Full silicon tracking system - provides $\geqslant$12 hits per track
- Fine-grained ECAL and HCAL optimised for particle flow reconstruction
- Superconducting solenoid is outside of the calorimeter
- Steel return yoke with muon chambers
- Forward detector region ($<$ 150 mrad) is reserved for Machine-Detector Interface (accommodates LumiCal)
- Support structures, cables and services are included in the model

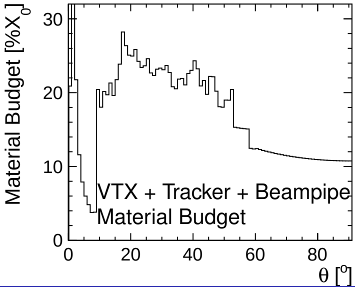
Vertex detector

- Silicon pixels: 25x25μm^2
- Single-point resolution: 3 μm
- 3 double layers in barrel: r = 17, 37, 57 mm
- 3 double endcap disks per side: z = 160, 230, 300 mm
- Material budget: 0.6% X_0 per double layer

Tracker detector

- Silicon pixel and microstrips detector
- Inner Tracker:
  - 3 barrel layers, 7 disks per side
- Outer Tracker:
  - 3 barrel layers, 4 disks per side
- Single-point resolution:
  - 7 μm x 90 μm
  - except 1st IT disk: 5 μm x 5 μm
- Material: 1.1-1.6% X_0 per layer



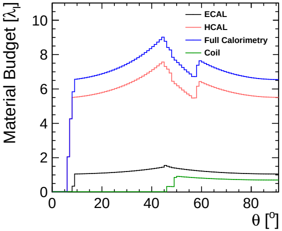


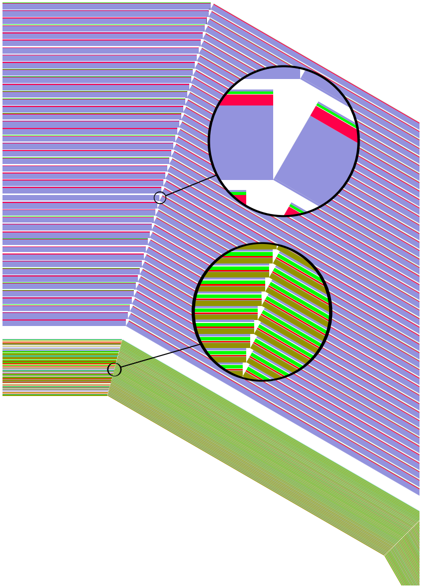
Electromagnetic Calorimeter

- Si-W sampling calorimeter
- cell size 5x5 mm^2
- 40 layers (1.9 mm thick W plates)
- Depth: 22 X_0, 1 λ_I, 20 cm

Hadronic Calorimeter

- Scintillator-steel sampling calorimeter
- cell size 30x30 mm^2
- 44 layers (19 mm thick steel plates)
- Depth: 5.5 λ_I, 117 cm (inspired by ILD)



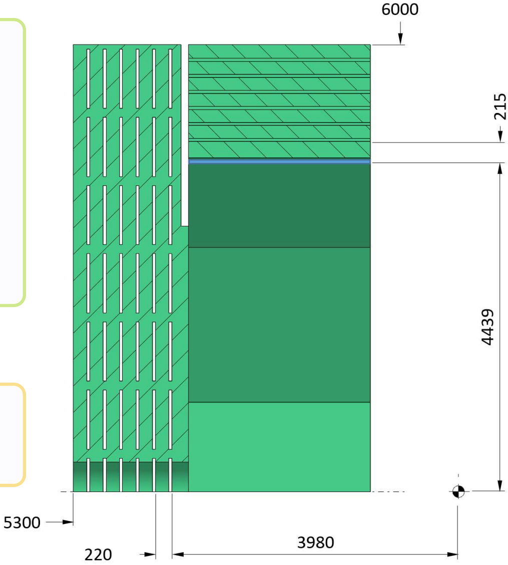


The magnet system

- Superconducting coil outside calorimeter (90 mm aluminium thick coil)
- Return yoke (1.5 m thick steel)
- The simulation model assumes:
  - 2 T homogeneous field in the tracker region
  - 1 T field in the yoke barrel
  - no field in the yoke endcaps

The muon system

- 6 layers of muon chambers (RPC)
- Cell size: 30 x 30 mm^2



Simulation and reconstruction software tools

- For performance study of the CLD detector for FCC-ee one can benefit from the fully functional and well tested iLCSoft software used by the CLIC and ILC community.

- Detector geometry description and event simulation: DD4hep
- Event Reconstruction: Marlin

- Track Pattern recognition: ConformalTracking
- Particle Flow Reconstruction: PandoraPFA

- Up-to-date geometry of detector model implemented in lcgeo package: FCCee_o1_v02

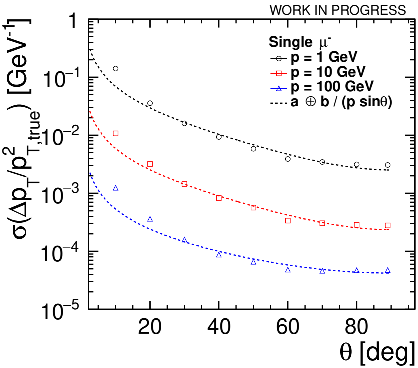
Tracking and calorimetry performances have been studied with full detector simulation

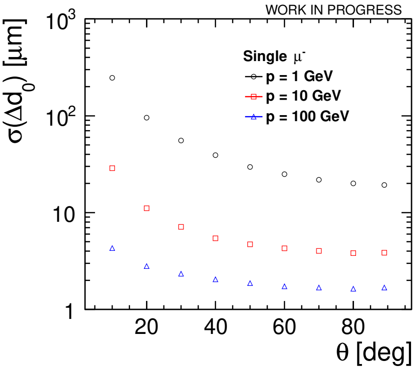
Tracking performance

- ✳Momentum and d_0 resolutions
- ✳Efficiency for single muons
- ✳Efficiency in complex events

Momentum and d_0 resolutions

- Statistics used: 10k single muons at fixed energy and θ for each datapoint

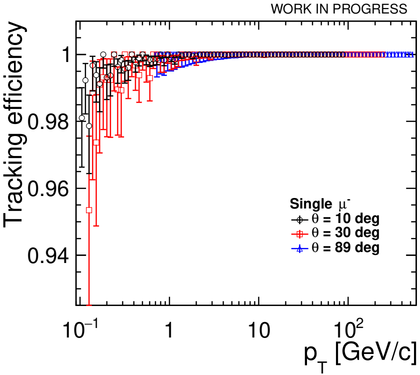


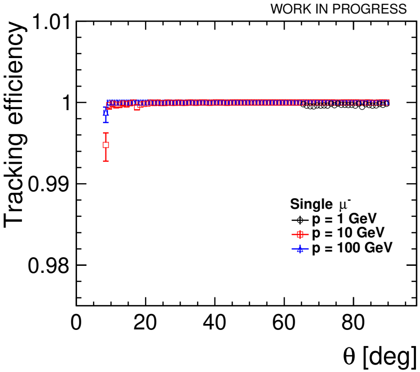


- Achieved resolutions for 100 GeV muons in the barrel
  - momentum resolution: $4\text{x}10^{-5}$ GeV^{-1}
  - transverse impact parameter resolution: $< 1\,\mu\text{m}$

Tracking efficiency for single muons

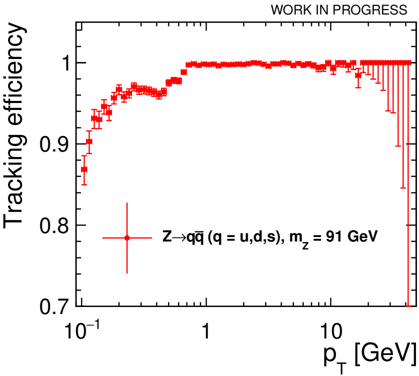
- Efficiency = fraction of reconstructed particles out of the reconstructable MC particles
- Reconstructable particles: stable MC particles with $p_T > 0.1$ GeV/c and $|\cos(\theta)| < 0.99$ which left at least 4 unique hits in tracking system
- Statistics used: 2M single muons

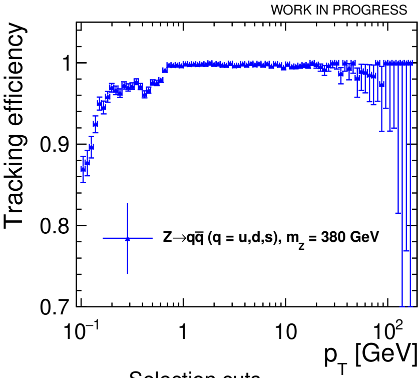




- Fully efficient tracking from 700 MeV over the whole θ range

- Efficiency = fraction of pure reconstructed particles out of the reconstructable MC particles
- Pure reconstructed particles: $\geqslant$75% of hits from track are associated to the simulated MC particle





- Fully efficient tracking from 700 MeV

Selection cuts

- $10 < \theta < 170$
- vertex R $<$ 50 mm

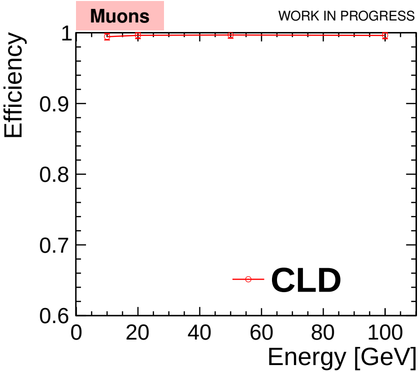
Calorimetry performance

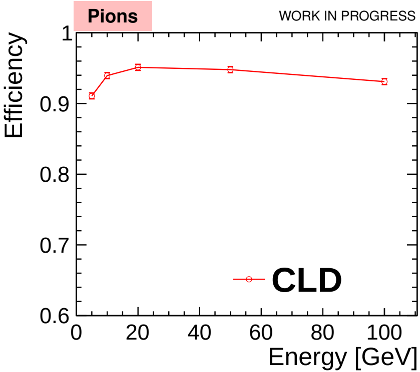
- ✳Single particle identification efficiency
- ✳Jet energy resolution

Single particle identification efficiency

- Efficiency = fraction of matched reconstructed particles out of the simulated MC particles:
  - reconstructed particle of the same type as simulated MC particle
  - angular matching: $\Delta\theta < 1$ mrad and $\Delta\phi < 2$ mrad
  - energy matching:
    - charged particles: $|p_T^{truth} - p_T^{PFO}| < 5\%\ p_T^{truth}$
    - photons: $\Delta E < 5 \times \sigma(\text{ECal}) \approx 0.75 \times \sqrt{E}$

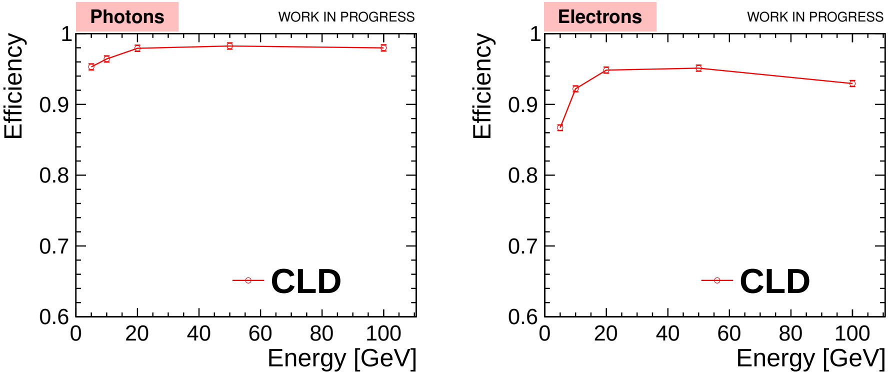
Sample: single particles with flat $\cos(\theta)$ distribution and fixed energy





- $>$99% muon efficiency and 93-95% pion efficiency for E$>$10 GeV
- Pion inefficiency due to misreconstruction of particle type

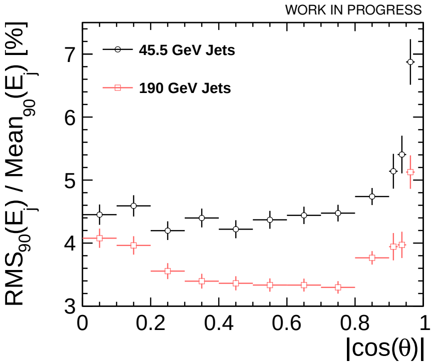
- Photon merging procedure is used to recover inefficiency due to photon conversion and electron Bremsstrahlung
- Pandora parameters were retuned in order to recover some electron inefficiency due to Bremsstrahlung

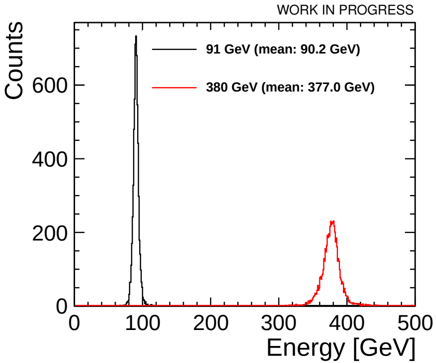


- $>$ 95% photons and 93-95 % electron efficiency for E$>$10 GeV

Jet Energy Resolution

- Z-like boson events decaying at rest into light quarks (two back-to-back jets)





- Jet energy resolution in barrel region:
  - 45.5 GeV jets: 4-4.5 %
  - 190 GeV jets: 3-4 %
- Total energy is reconstructed with 1% accuracy:
  - 91 GeV: 90.2 GeV
  - 380 GeV: 377.0 GeV

Jet energy (E_j) is measured as a half of total energy (E_{jj}) of Z$\rightarrow q\bar{q}$ (q=u,d,s) di-jet event

$$\frac{\mathrm{RMS}_{90}(E_j)}{\mathrm{mean}_{90}(E_j)} = \frac{\mathrm{RMS}_{90}(E_{jj})}{\mathrm{mean}_{90}(E_{jj})}\sqrt{2}$$

Summary and Outlook

Summary

- The CLD detector design for the Conceptual Design Report has been presented
- Tracking and calorimetry performance studies with full detector simulation demonstrates excellent overall detector performance

Outlook

- Further detector performance simulation studies
  - flavour tagging performance
  - overlay of incoherent pairs (in progress) and synchrotron radiation backgrounds
- Full simulation studies of different physics processes
  - software framework and detector model available
- Engineering studies
  - cooling studies of all subdetectors (no power pulsing)
  - ECAL optimisation (technology choices, number of layers)
  - detector opening / maintenance scenarios, impact for detector layout

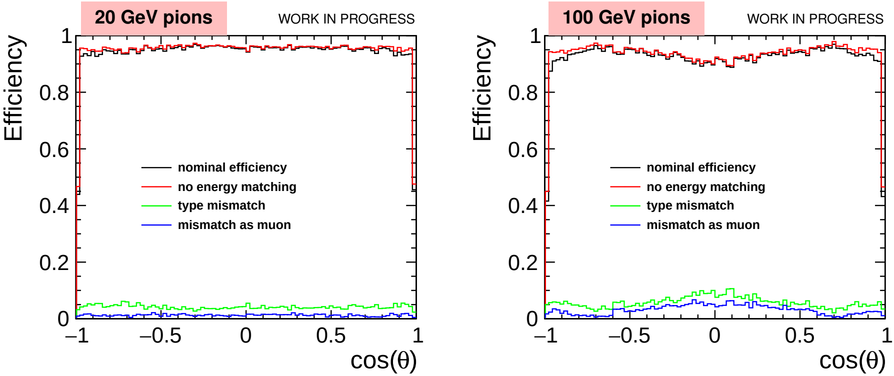
Thank you for your attention!

BACKUP

Overall dimensions of CLIC and FCC-ee detectors

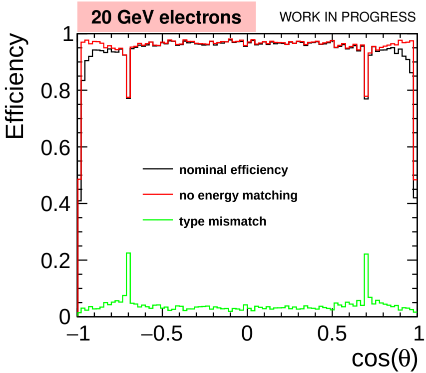
	CLICdet		CLD
VTX Barrel	31-60 mm	$\Longrightarrow$	17-59 mm
VTX Endcap	Spirals	$\Longrightarrow$	Disks
Tracker radius	1486 mm	$\Longrightarrow$	2100 mm
ECAL thickness	40 layers, 22 X_0	$\Longrightarrow$	40 layers, 22 X_0
HCAL thickness	60 layers, 7.5 λ_I	$\Longrightarrow$	44 layers, 5.5 λ_I
Yoke thickness	1989 mm	$\Longrightarrow$	1521 mm
MDI (forward region)		$\Longrightarrow$	$<$ 150 mrad
Solenoid field	4 Tesla	$\Longrightarrow$	2 Tesla

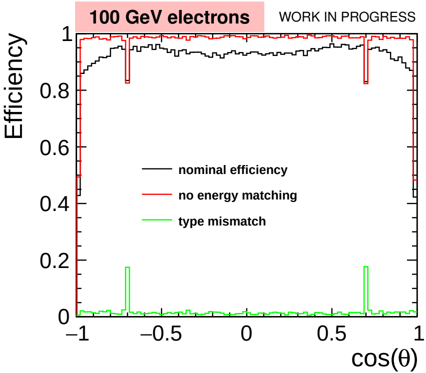
- Pion ID efficiency and inefficiency as function of cos(θ)



- High momentum pions more often are misreconstructed as muons in barrel

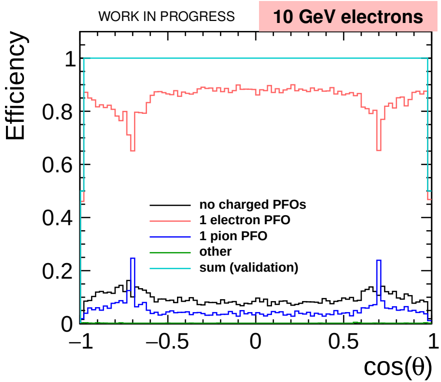
- Electron ID efficiency and inefficiency as function of cos(θ)

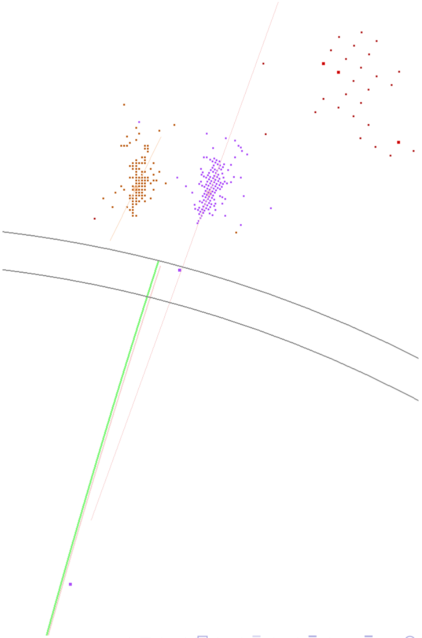




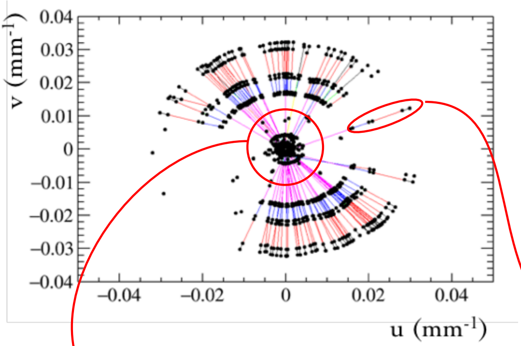
- Inefficiency for high-momentum electrons can be recovered by better Bremsstrahlung recovery algorithm

Electron identification efficiency (Pandora track-cluster association algorithm)





- in 10-13% of events no charged PFO is reconstructed in the event
- track-cluster association algorithm fails to attach track to cluster (as shown on the right)
- in 3-6% of events fake "pion" is reconstructed
- in calorimeter transition region a small fraction of electrons is reconstructed as "pions"



Track fitting is done in the conformal space:

$$u = \frac{x}{x^2 + y^2} \qquad v = \frac{y}{x^2 + y^2}$$

Cellular automaton is used to perform straight line search

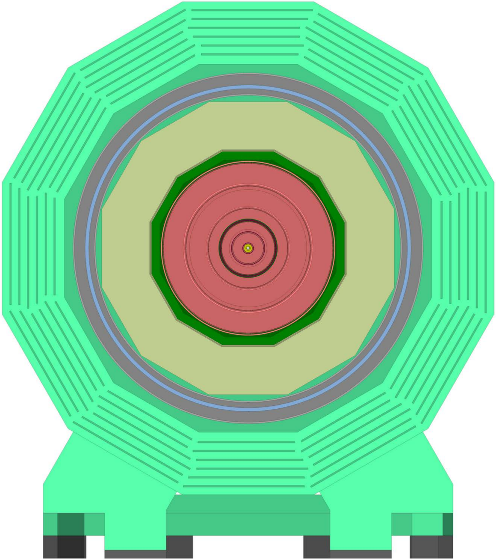
Hits from the Vertex

Hits from the Tracker

- Conformal tracking is used as the main track pattern recognition algorithm at CLIC

LCWS presentation about CLIC Conformal Tracking performance

CLD detector layout: x-y view



CLD vs CLICdet overall dimensions

Concept	CLICdet	CLD
Vertex inner radius [mm]	31	17
Tracker technology	Silicon	Silicon
Tracker half length [m]	2.2	2.2
Tracker outer radius [m]	1.5	2.1
Inner tracker support cylinder radius [m]	0.575	0.675
ECAL absorber	W	W
ECAL X_0	22	22
ECAL barrel r_{min} [m]	1.5	2.15
ECAL barrel Δr [mm]	202	202
ECAL endcap z_{min} [m]	2.31	2.31
ECAL endcap Δz [mm]	202	202
HCAL absorber	Fe	Fe
HCAL λ_{I}	7.5	5.5
HCAL barrel r_{min} [m]	1.74	2.40
HCAL barrel Δr [mm]	1590	1166
HCAL endcap z_{min} [m]	2.4	2.4
HCAL endcap Δz [mm]	1590	1166
Solenoid field [T]	4	2
Solenoid bore radius [m]	3.5	3.7
Solenoid length [m]	8.3	7.4
Overall height [m]	12.9	12.0
Overall length [m]	11.4	10.6