Tracking Performance Studies with the CLD Detector

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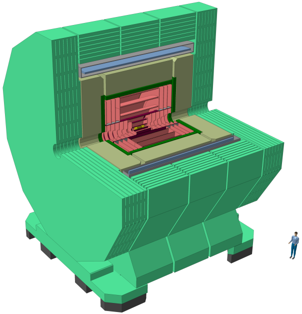
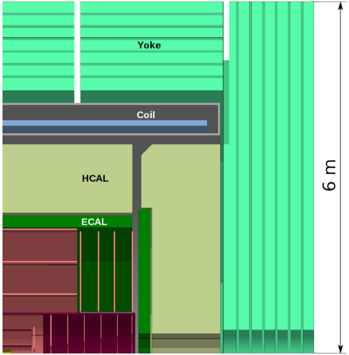
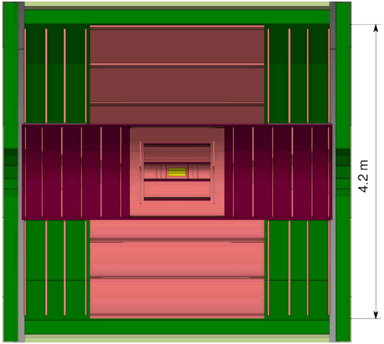
Detector Concepts Meeting – 23 September 2024

Goals

- Detector optimisation by defining different geometries for vertex and tracker
- Study detector tracking and vertexing performance for physics and sensitivity to new physics
- **Full Simulation** is needed to have more precise results, the detector concept CLD is used for these studies





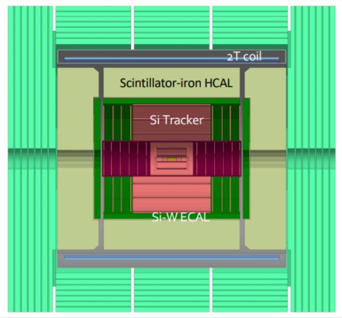


Outlook

1. CLD detector

2. Tracking Resolution
   - Effect of smaller Beam Pipe
   - Effect of vertex spatial resolution
   - Effect of shrunk tracker
   - Effect of stronger magnetic field

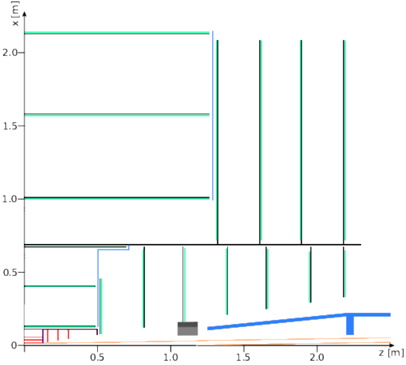
CLD* detector concept at FCCee



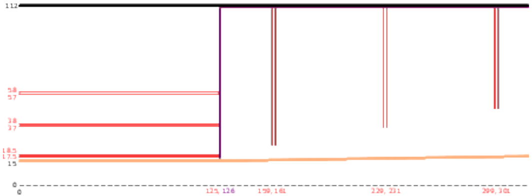
- Consolidated option based on the detector design developed for CLIC detector
  - **All silicon vertex detector and tracker**
  - 3D-imaging highly-granular calorimeter system
  - Coil outside calorimeter system
  - Resistive plate chambers muons detector

*CLIC-like detector

CLD tracker geometry



- **Vertex Detector** with 3 μm spatial resolution pixels



- **Inner and Outer Silicon Tracker**, mostly 50 μm pitch strips
  - 3 short and 3 long barrel layers, 7 inner and 4 outer endcaps
  - 200 μm Silicon thickness, 50 μm $\times$ 0.3 mm cell size, 7 μm $\times$ 90 μm single point resolution (except first inner tracker disk, 5 $\times$ 5 μm^2)
- Tracking optimisation with **full silicon tracker**

  - larger material budget
  - No space for PID[a]

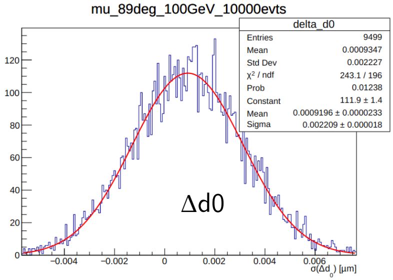
  - robust technology
  - high single point resolution
  - tune to sustain higher particle rate

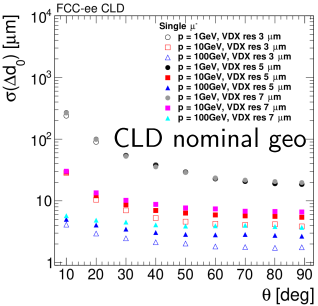
[a] Particle identification detector

More details on CLD_o1_v04

Tracking resolution

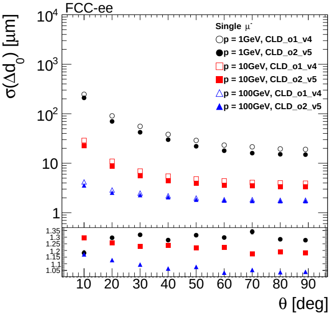
- Simulate **particle gun** events
  - Single particle event with fixed momentum and θ and flat ϕ
  - Done with muons, electrons and pions
- Matching reconstructed track – simulated particle
- Calculation of resolution: $\sigma(\ \Delta = \text{reco - true})$
  - For p and pT, resolution: $\sigma(\ (\Delta = \text{reco - true})\ /\ \text{true}^2)$
- Calculate resolutions by changing VTX resolution
  - Defined as the smearing for simulated hits with resolution VTX values (3 μm, 5 μm,...) as the Gaussian width





Effect of shortened vertex detector and Beam Pipe material budget

Beam Pipe and Vertex geometry



- Improvement of the d_0 resolution in the new geometry (o2_v05)
  - **Smaller vertex radius compensates fully for the increased material budget in beam pipe**

CLD_o1_v04 (nominal geometry)

- Beam Pipe **radius**: **15** mm
- Beam Pipe **material**: Beryllium
- Beam Pipe **thickness**: **1.2** mm + 5 μm gold
- **X/X0** = **0.45 %**

CLD_o2_v05

- Beam Pipe **radius**: **10** mm
- Beam Pipe **material**: AlBeMet 0.35 mm + paraffin 1 mm + AlBeMet 0.35 mm
- Beam Pipe **thickness**: **1.7** mm + 5 μm gold
- **X/X0** = **0.61 %** ⇒ **+ 33 % material budget**

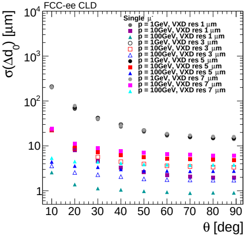
Vertex Barrel [mm]	R_1	R_2	R_3	L
o1_v04	17.5	37	57	125
o2_v05	**13.0**	**35**	**57**	**109**

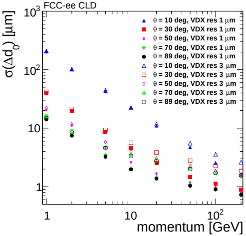
CLD_01_v04: BeamPipe material 100 % Be, BeamPipe radius = 15 mm
CLD_02_v05: BeamPipe material AlBeMet + paraffin, BeamPipe radius = 10 mm

Effect of vertex spatial resolution

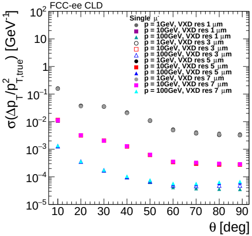
d_0 & pT resolution – single μ^- – CLD_o2_v05 (10k events)

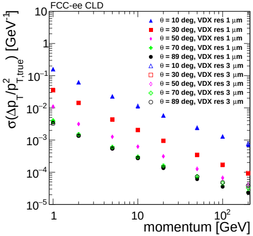
- d_0
  As expected, very sensitive to intern layer, particularly at high p_T
  Material budget is dominant for low p_T



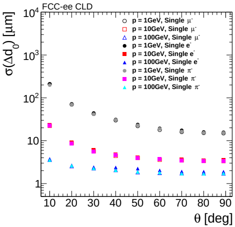


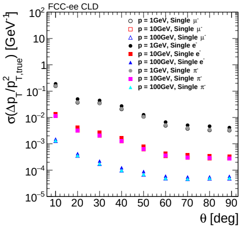
- p_T
  Effect is smaller, some effect at high impulsion in barrel





- μ^-, e^- & π^- – VXD resolution $= 3\ \mu m$

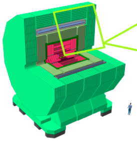




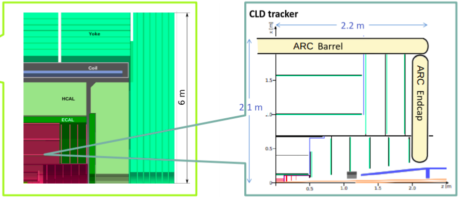
Digitisation is made by smearing simulated hits with spatial resolution values as the Gaussian width

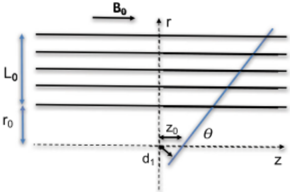
CLD with PID

Tracker geometry – CLD_o2_v05 & CLD_o3_v01 = RICH* and adapted trackers



CLD detector





doi.org/10.1016/j.nima.2018.08.078

⟹ **Need space**

Outer Tracker Barrel [mm]	R_1	R_2	R_3
o2_v05	1000	1568	2136
o3_v01	**1000**	**1446.8**	**1849.2**

Outer Tracker Endcap [mm]	Z_0	Z_1	Z_2	Z_3
o2_v05	1310	1617	1883	2190
o3_v01	**1310**	**1547**	**1752**	**1990**

Outer tracker barrel and endcap were shrunk

$$\Delta d_0|_{res} \approx \frac{3\sigma_{r\phi}}{\sqrt{N+5}}\sqrt{1+\frac{8r_0}{L_0}+\frac{28r_0^2}{L_0^2}+\frac{40r_0^3}{L_0^3}+\frac{20r_0^4}{L_0^4}}$$

$$\frac{\Delta p_T}{p_T}|_{res} \approx \frac{12\sigma_{r\phi}p_T}{0.3B_0L_0^2}\sqrt{\frac{5}{N+5}}$$

⇒ **lever arm reduced by 10 %**

⇒ p_T **res should degrade by** $\approx 20\%$

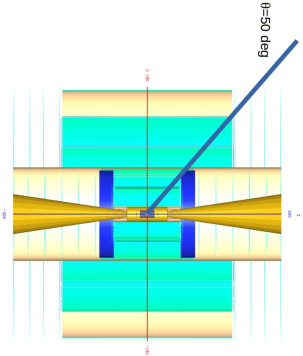
CLD_03_v01: CLD_02_v05 with shrunk Outer Tracker + PID detector

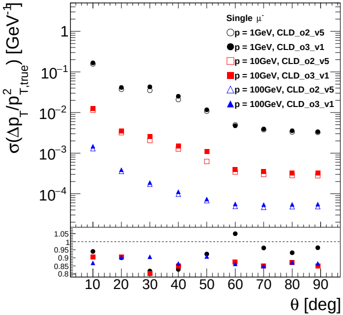
*10.1016/j.nima.2019.02.009 (use Cherenkov radiation)

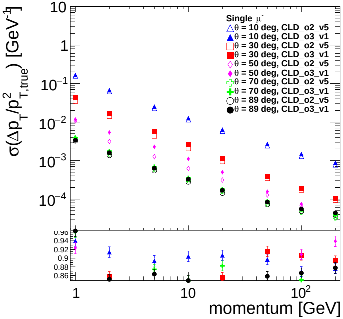
CLD with PID

Tracker geometry – CLD_o2_v05 & CLD_o3_v01

- p_T resolution depend mainly on lever arm
- Differences observed are compatible with analytic formula ≈ **15 %**
- For $\theta = 50$ °: transition Barrel / Endcap





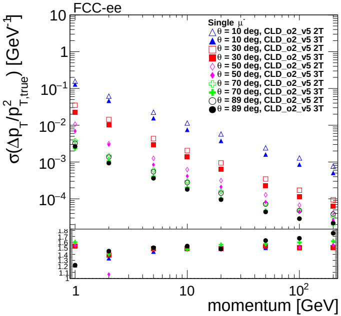


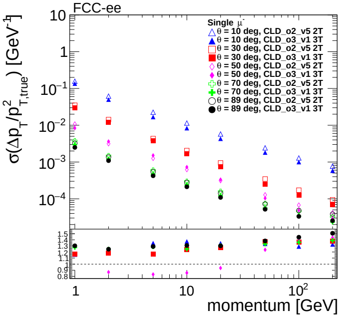
CLD_03_v01: CLD_02_v05 with shrunk Outer Tracker + PID detector

Tracking resolution

Effect of magnetic field

- Magnetic field of **2 T** is imposed for Z peak ($\sqrt{s} = 91$ GeV)
- **2 T** to **3 T** (without any consideration of whether it is possible) increase p_T resolution and compensate the loss of p_T resolution caused by the shrunk tracker





CLD: magnetic field = 2 T

Tracking resolution

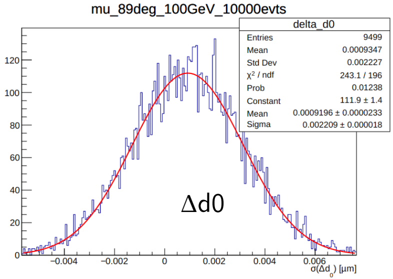
Summary

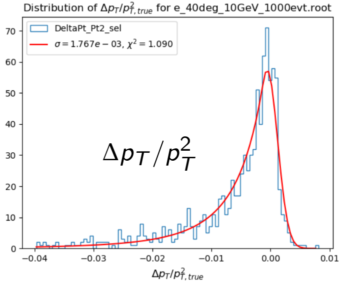
- Study track resolution with different single point resolution and tracker (beam pipe) geometries
- Several spatial resolution for vertex tested, also for 1 micron, to test extreme case (while probably not realistic)
- Improvement of the d0 resolution in the geometry with smaller beam pipe (CLD_o2_v05)
- $\approx$ 15 % degradation of p_T resolution in CLD_o3_v01 with ARC
- Can be recovered by increasing magnetic field to 3 T, p_T resolution even better
- Next step will be to study impact of geometry on physics analysis

Backup

Tracking resolution

- Simulate **particle gun** events
  - Single particle event with fixed momentum and θ and flat ϕ
  - Done with muons, electrons and pions
- Matching reconstructed tracks – simulated particle
- Calculation of resolution: $\sigma(\ \Delta = \text{reco - true})$
  - For p and pT, resolution:
    $\sigma(\ (\Delta = \text{reco - true})\ /\ \text{true}^2)$
  - Resolution is the width of the gaussian fit, or crystal ball fit for electron momentum
- Calculate resolutions by changing VTX resolution
  - Defined as the smearing for simulated hits with resolution VTX values (3 μm, 5 μm,...) as the Gaussian width



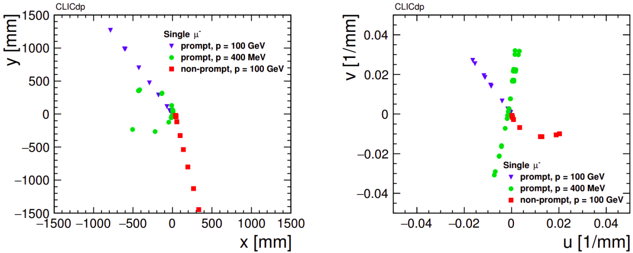


Tracking

Conformal Tracking*

- **Conformal mapping:** coordinates (x, y) in Euclidean space are converted to coordinates (u, v) in conformal space, circles passing through the origin are transformed into straight lines

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



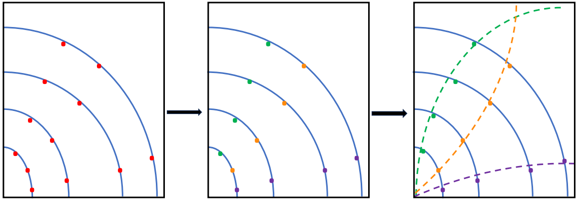
- **Cellular Automaton Track Finding:** for pattern recognition

*Conformal Tracking @CLIC

Tracking

Track Finding

- **Sequential track seeding and findings steps:** hits not part of a track after step N are used in step N+1



- **VXDBarrel:** build track seeds in the vertex barrel
- **VXDEndcap:** extend track seed through the vertex endcaps
- **LowerCellAngle1:** build track candidates with tight cuts for high-p_T tracks
- **LowerCellAngle2:** build track candidates with looser cuts to reconstruct low-p_T tracks
- **Tracker:** extends all existing partial tracks through the tracker
- **Displaced:** build additional tracks with optimised cuts for displaced tracks from all the leftover hits