Towards CLD Tracker optimisation

Jeremy Andrea, Gaelle Sadowski, Auguste Besson, Ziad El Bitar

Thanks to Leonhard Reichenbach, Andre Sailer, Alvaro Tolosa, Brieuc François, Michele Selvaggi

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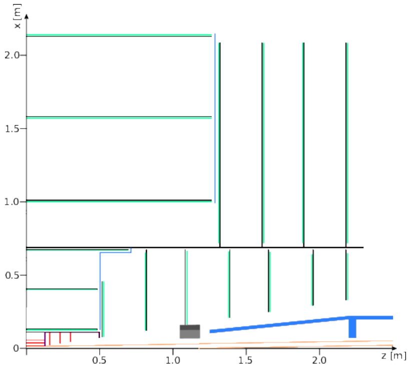
Introduction and motivation

Objectives:

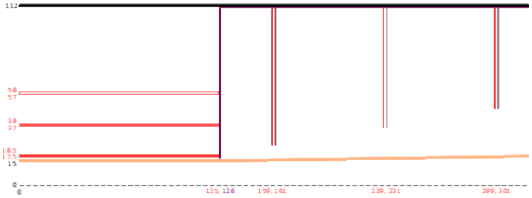
- Vertex and tracker optimisation for different geometries
- Guidline for R&D on full silicon tracker
- Candle for physics performance : increasing level of complexity (Tracking, Vertexing, flavour tagging, full analysis)
- Chosen approach: full simulation, for more precise results, use of CLD here

- **Outline:**
  - Study of tracking resolution for different CLD geometries
  - First attempts for long lived particle reconstruction (Heavy Neutral Lepton)

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 × 0.3 mm cell size, 7 μm × 90 μm single point resolution (except first inner tracker disk, 5 × 5 μm^2)
- Tracking optimisation with **full silicon tracker**
  - material budget
  - No space for PID
  - robust technology
  - high single point resolution
  - tune to sustain higher particle rate

More details on CLD_o1_v04

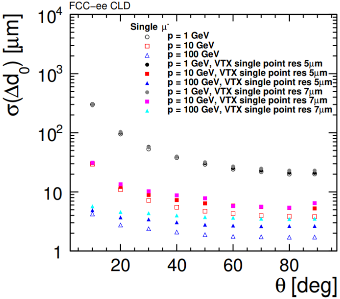
More CLD geometries on talk by A.Sailer

Tracking Performance

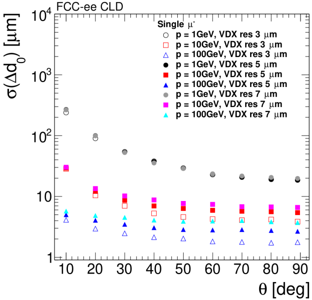
First step: reproduce performance plot with different framework – CLD_o1_v04 geometry

CLD - A Detector Concept for the FCC-ee

arXiv:1911.12230v3



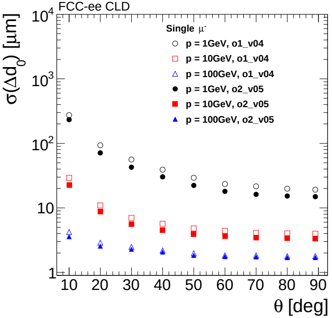
Current study



- New implementation of the performance plots gives comparable results than the CLD paper
- Study of new geometries is possible
  - Smaller and more realistic beampipe, and adapted vertex detector
  - Add of PID and shortened trackers
  - fast / full simulation comparisons for prompt tracks

Effect of shortened vertex detector and BeamPipe material budget

BeamPipe and Vertex geometry – CLD_o1_v04 & CLD_o2_v05 = smaller more realistic BeamPipe, adapted Vertex



- 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**

More details on CLD_o1_v04

More CLD geometries on talk by A.Sailer

CLD_o1_v04

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

CLD_o2_v05

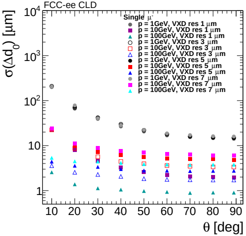
- BeamPipe **radius**: **10** mm
- BeamPipe **material**: AlBeMet 0.35 mm + paraffin 1 mm + AlBeMet 0.35 mm
- BeamPipe **thickness**: **1.7** mm + 5 μm gold
- **X/X0** = **0.61 %** $\Rightarrow$ **+ 33 % material budget**

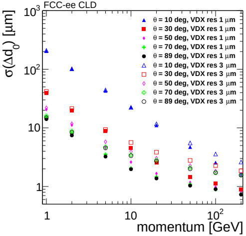
Vertex Barrel [mm]	R_1	R_2	R_3	L
o1_v04	17.5	37	57	125
o2_v05	**13.0**	**35**	**57**	**109**

Effect of vertex spatial resolution

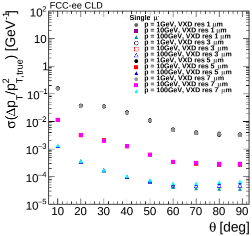
d_0 & pT resolution – single μ^- – CLD_o2_v05 (10k events)

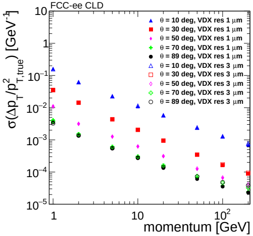
- d_0
  As expected, very sensitive to intern layer, particularly at high p_T
  Material budget is dominant for low p_T



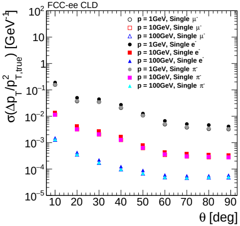


- p_T
  Effect is smaller, some effect at high impulsion in barrel





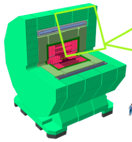
- e^- & π^-



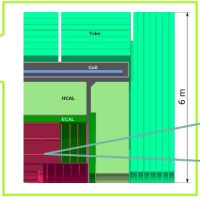
Digitisation is made by smearing simulated hits with spatial resolution values as the Gaussian width

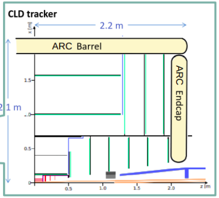
CLD with PID

Tracker geometry – CLD_o2_v05 & CLD_o3_v01 = ARC and adapted trackers



CLD detector





$\Longrightarrow$ **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**

Inner tracker endcap was shrunk as well

doi.org/10.1016/j.nima.2018.08.078

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

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

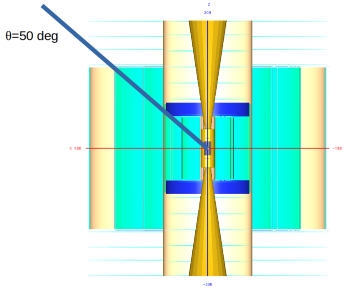
$\Rightarrow$ **lever arm reduced by 10 %**

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

CLD with ARC see this talk by A.Tolosa

CLD with PID

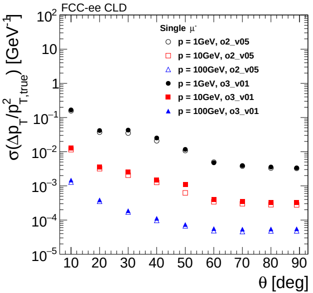
Tracker geometry – CLD_o2_v05 & CLD_o3_v01 = ARC and adapted trackers

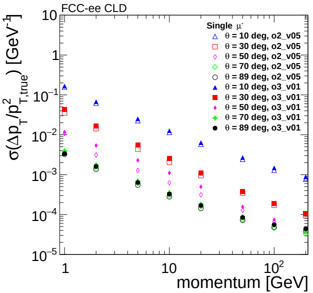


relative diff	10 °
10 GeV	10,5 %
100 GeV	15 %

relative diff	89 °
10 GeV	17.8 %
100 GeV	15.5 %

- p_T resolution depend mainly on lever arm
- Differences observed are compatible with analytic formula
- For $\theta = 50$ °, tracks fall into a crack in the tracker geometry





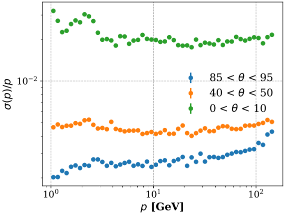
CLD with ARC see this talk by A.Tolosa

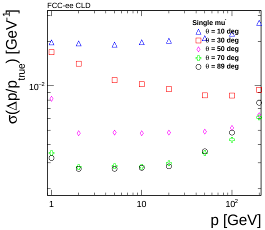
Comparison with Fast Simulation

Full Sim & Fast Sim tracking performance – impulsion resolution

Full Sim

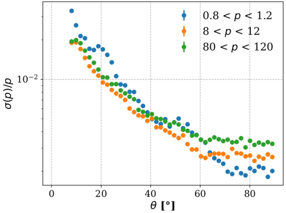
Fast Sim

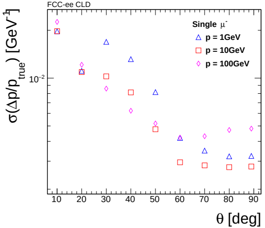




10 GeV 89° = 7 % difference

10 GeV 70° = 3 % difference





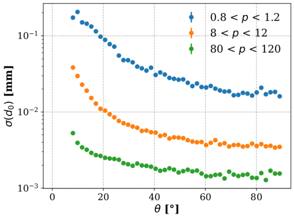
- Impulsion resolution is comparable for FCC-CLD fast and full simulation

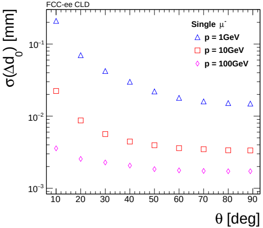
Comparison with Fast Simulation

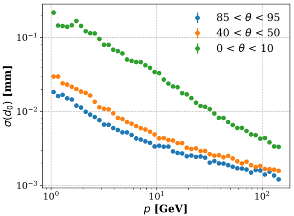
Full Sim & Fast Sim tracking performance – d_0 resolution

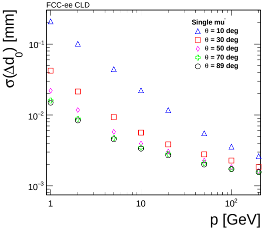
Full Sim

Fast Sim









10 GeV 89° = 6.7 % difference
10 GeV 70° = 6.9 % difference

- d_0 resolution is comparable for FCC-CLD fast and full simulation

Tracking performance

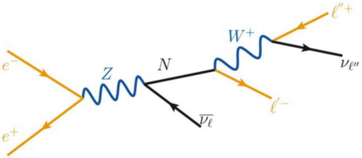
Summary

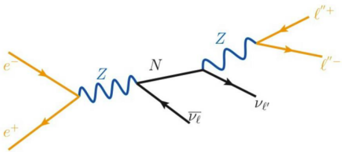
- Study track resolution with different single point resolution and tracker (beam pipe) geometries
- Code validated by reproducing CLD paper results (geometry CLD_o1_v04)
- Several spatial resolution for vertex tested, also for 1 micron, to test extreme case (while probably not realistic)
- Improvement of the d0 resolution in the new geometry (CLD_o2_v05) with smaller beam pipe
- $\approx$ 20 % degradation of p_T resolution in CLD_o3_v01 with ARC
- Track resolutions are comparable for FCC-CLD fast and full simulation, for prompt tracks

HNL studies

See talk by J.Andrea G.Sadowski

- Generation of Long Lived Particle within the Heavy Neutral Lepton model
- Inherits from FCCee paper (Alimena&al arXiv:2203.05502v4)



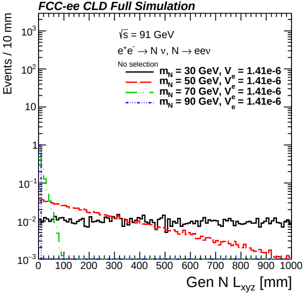


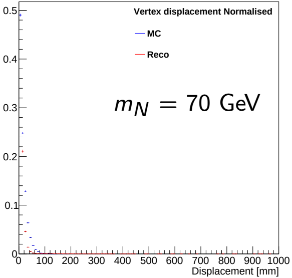
- Production made in the di-electron channels
  - Allows for some comparisons with fastsim potentially
  - Benefits from existing expertise
  - Analysis possibly to be ported on other LLP models,
  - Some events to play with...

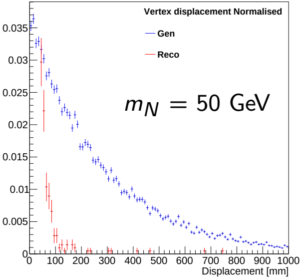
HNL studies

Simulation issue

- We had issues to simulate displaced vertices, HNL vertices were simulated at IP (0,0,0)
- We have tried with HEPMC2 format with MadGraph, but simulation compatible with HEPMC3
- Madgraph is not interfaced with HEPMC3. **Solution :** generate lhe event (parton) with MadGraph, then run pythia standalone to produce HEPMC3 file
  - Simulation of displaced vertex require status code 2 for the HNL, while it is status 22 out of pythia => script to **change by hand the status in** HEPMC3







HNL studies

Reconstruction issue

- **Reconstruction issue with CLD_o2_v05 geometry**, smaller radius for first double layer in vertex detector required re-optimisation of track seeds
  - Larger distance between first and second double layer caused a difficulty to extrapolate tracks to second double layer ⇒ Corrected by changing maximum distance to 0.05 in Conformal Tracking*
  - **CLD_o1_v04 geometry used in this HNL study**

*Leonhard Reichenbach, Andre Sailer

HNL studies

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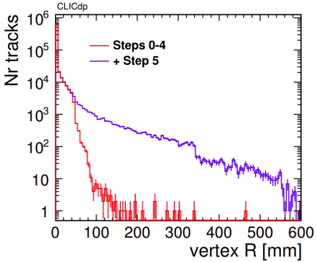
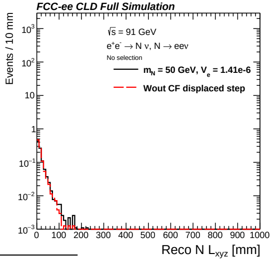
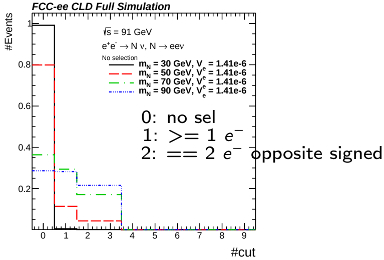
  - Larger distance between first and second double layer caused a difficulty to extrapolate tracks to second double layer ⇒ Corrected by changing maximum distance to 0.05 in Conformal Tracking*
  - **CLD_o1_v04 geometry used in this HNL study**
- **No track reconstruction is observed beyond a displacement of 100mm.** Whereas, Conformal Tracking previous study with CLIC dectector arXiv:1908.00256v1 suggests a significantly effective reconstruction of displaced tracks
  - **Attempt to re do without displaced step (step 5) in Conformal Tracking gave the same result...**







*Leonhard Reichenbach, Andre Sailer

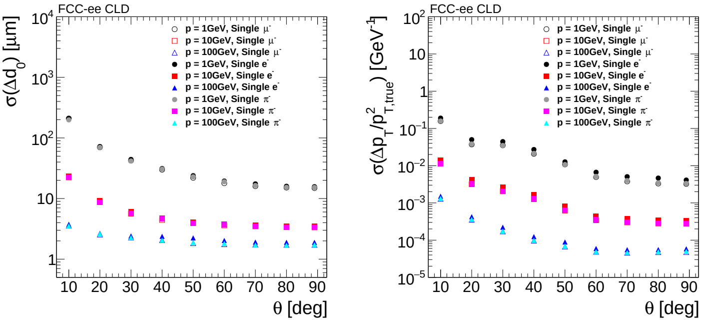
Summary & Outlook

- Method to generate HNL events with correct displacement implemented and tested
- Absence of reconstructed tracks after 100 mm displacement
- Next steps
  - Debug Conformal Tracking
  - Study electron/track reconstruction efficiencies
  - Study displaced vertex reconstruction efficiency
  - Reproduce fast sim analysis
  - Study impact of tracker geometry on physics performance

Backup

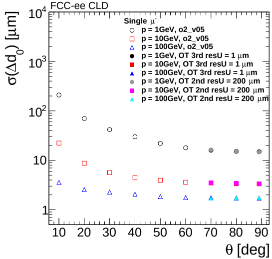
Tracking performance

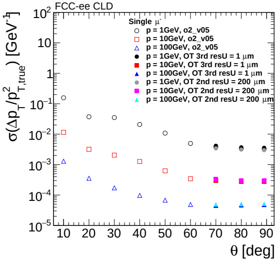
Tracking for electrons and pions



Tracking Performance

Tracker geometry – CLD_o2_v05





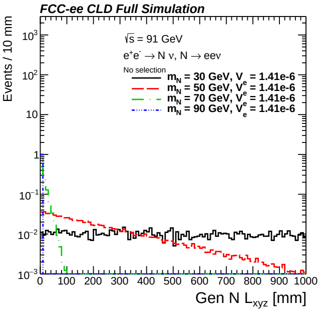
$$\Delta d_0|_{res} \approx \frac{3\sigma_{r\phi}}{\sqrt{N+5}}\sqrt{1+\frac{8r_0}{L_0}+\frac{28r_0^2}{L_0^2}+\frac{40r_0^3}{L_0^3}+\frac{20r_0^4}{L_0^4}}$$

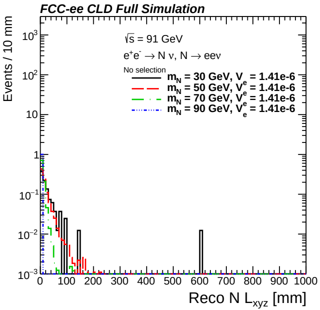
$$\frac{\Delta p_T}{p_T}|_{res} \approx \frac{12\sigma_{r\phi}p_T}{0.3B_0L_0^2}\sqrt{\frac{5}{N+5}}$$

- p_T resolution depend mainly on lever arm
- increase resolution on only one layer does not have a big effect on total resolution

HNL studies

Comparison with Delphes arXiv:2203.05502v4





- Gen level similar to the reco FastSim sample ⇒ does FastSim account for tracking efficiency?
- Reco vertex in FullSim shows a large deficit of tracks at high displacement (>100mm)