Status of and plans for CLD detector (re-)optimization studies

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CERN, Uni Bonn

International Workshop on Future (Linear) Colliders
May 17, 2023

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Disclaimer

CLD is a detector concept for a circular collider **but**

- It has a strong linear collider heritage
- The type of work presented here is mostly independent from the type of collider
- Our software eco-systems are (supposed to be) converging

This work might be able to help you and can profit from your input!

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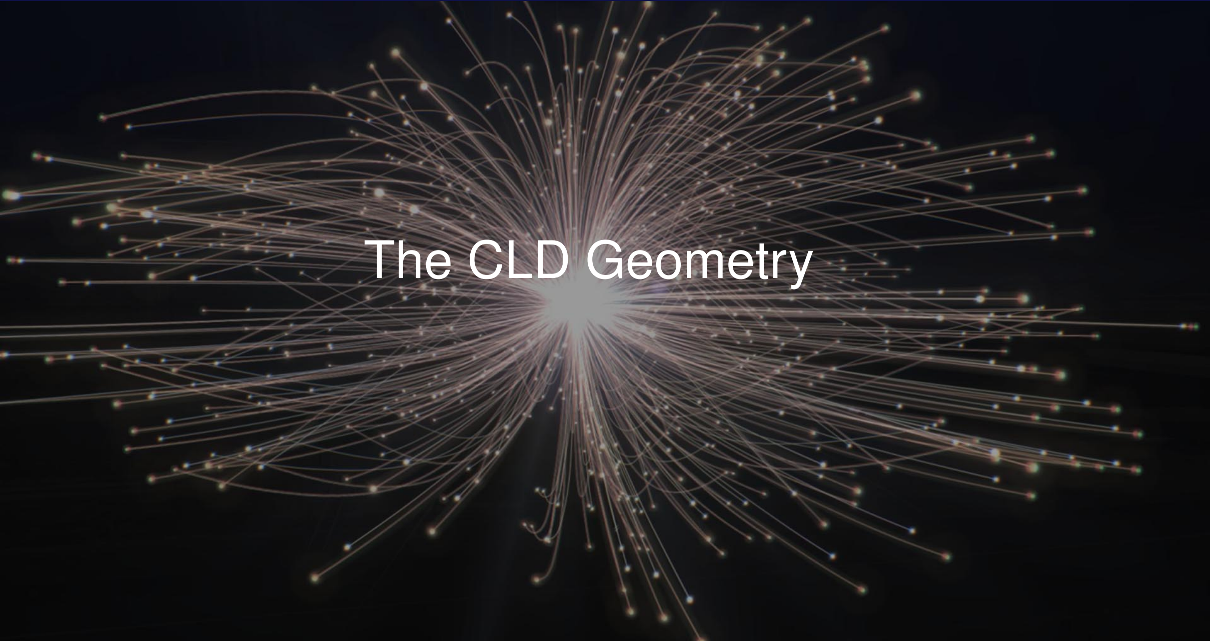
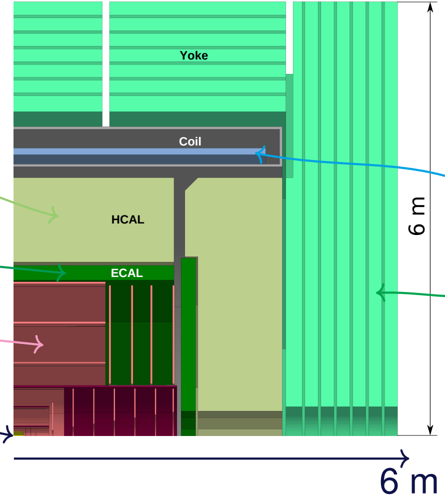
The CLD Geometry



Detector for FCCee

General purpose detector for Particle Flow reconstruction [1]

- Steel–Scintillator HCal with 3 cm cell-size
- Silicon–Tungsten ECal with 5 mm cell-size
- Silicon Tracker, mostly 50 µm pitch strips
- Vertex Detector with 25 µm pixels

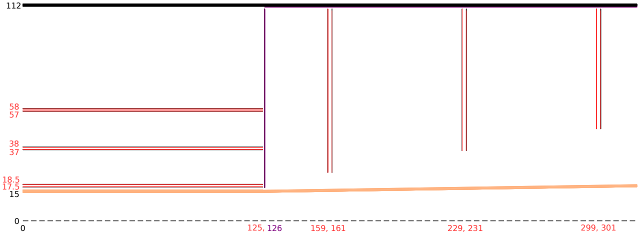


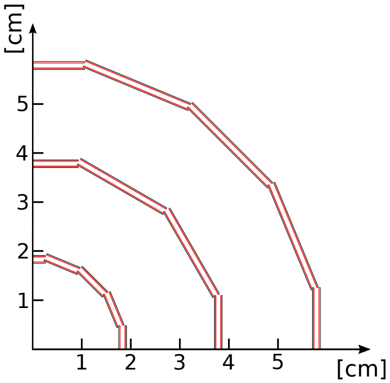
- Superconducting Solenoid of 2 T
- Iron Yoke with RPCs for Muon ID

Vertex Detector

FCCee_o1_v04

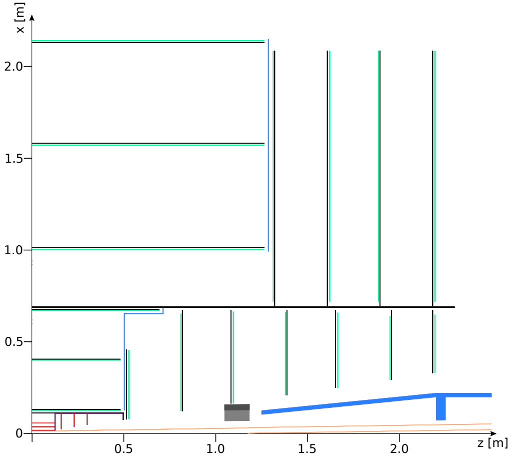
- Silicon vertex detector: precise vertex reconstruction
- $25 \times 25\ \mu m^2$ pixels, 3 µm single point resolution
- 50 µm silicon thickness (+235 µm support etc.)
- Double layers (0.3%X_0 per detection layer)
- $R_{in} = 17.5$ mm (old beampipe)





Silicon Tracking

- Inner and Outer Tracker
  - Support tube for extraction with beam-pipe assembly
- 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, 5×5 μm^2)
- At least 8 hits for $\theta > 8.5^\circ$
- Material budget: 1.1 % – 2.2 % X_0 per layer (including overlaps)
- Some studies for re-scaling were done (cf. [1] and later)



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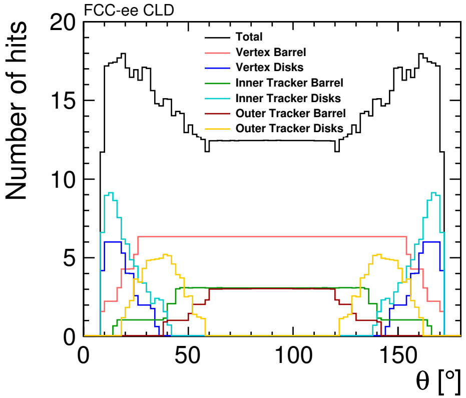

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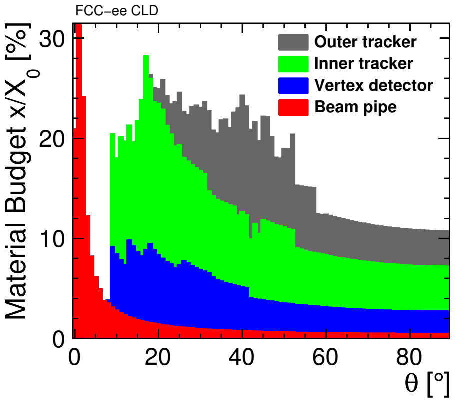
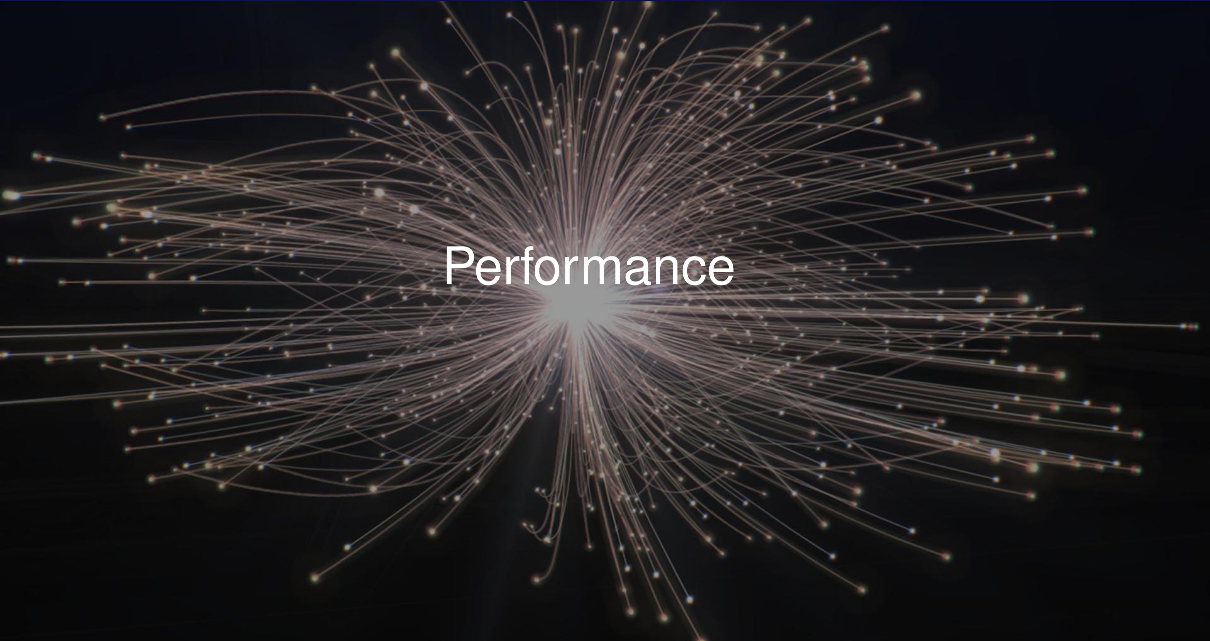




Performance

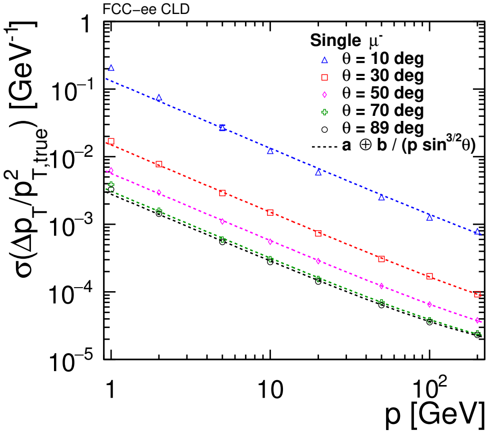
Performance Requirements and Studies

- Performance of CLD detector detailed in the note [1]
- Requirements for FCC-ee detector [2]

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_\mathrm{T}) \sim 2\times10^{-5} \oplus 1\times10^{-3}/(p_\mathrm{T}\sin\theta)$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p\sin^{3/2}\theta)\mu\mathrm{m}$
$H \to q\bar{q}, VV$	$\mathrm{BR}(H \to q\bar{q}, VV)$	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3-4\%$
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%(\mathrm{GeV})$

Tracking

- Momentum resolution
- Impact parameter resolution
  - Also estimated for larger material budget in the vertex detector
- Single particle efficiency w.r.t. transverse momentum
- Single particle efficiency w.r.t. radius
- Efficiency in jets
- Re-scaling Studies: $R_{max} \in (2.1, 2.0, 1.9, 1.8)$ m



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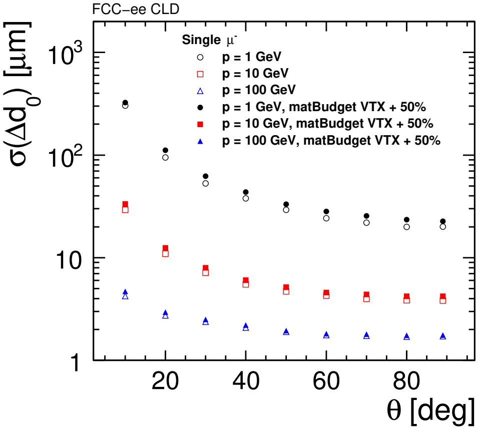

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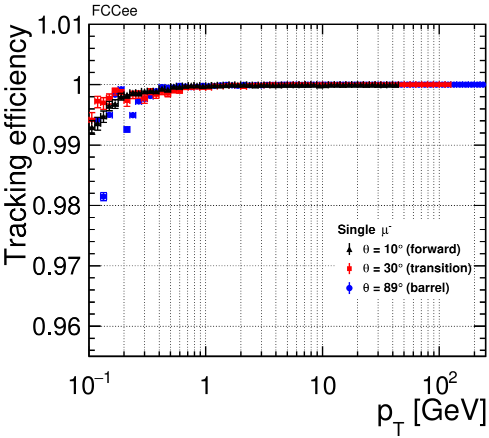

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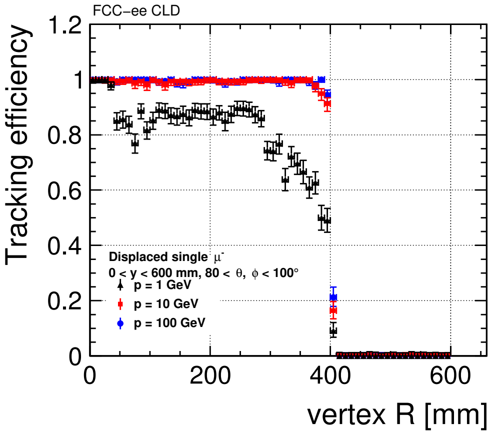

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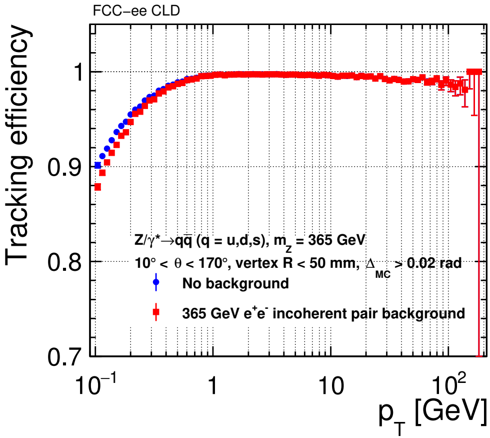

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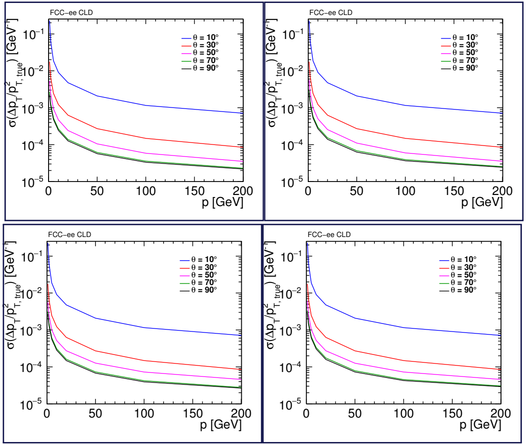
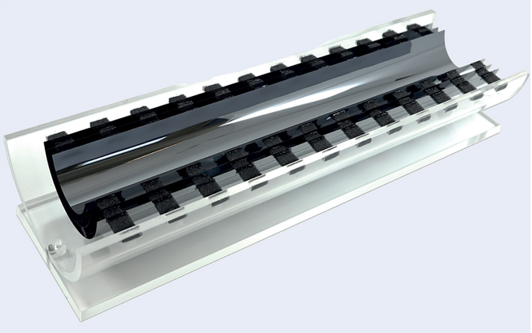


Optimisation Plans

Optimisation Plans: Detector

Vertex & Tracker:

- Vary material budget ($0.3\%X_0 \rightarrow 0.05\%X_0$?)
- Vary single-point resolutions
- Pay special attention to the performance at lower energies, e.g. at the Z-pole
- Study influence of beam pipe material

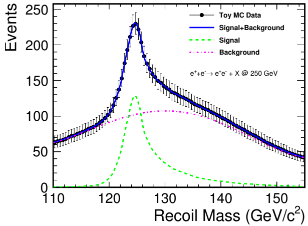


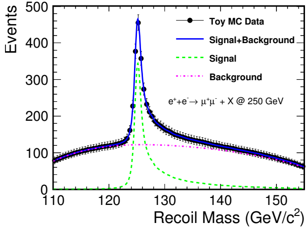
Inspiration? ALICE ITS3

Optimisation Plans: Software

Improve electron track reconstruction

- ACTS-based tracking in Key4hep
- Additional track fit for electrons with a Gaussian Sum Filter (GSF)
- Matching of bremsstrahlung photons
- $\rightarrow$Improved p_{T} and impact parameter resolution





Taken from 1604.07524 [3]

Performance Evaluation Plans

- Create single particle and physics analysis based benchmarks
  - ZH-recoil and $WW/e\nu W$
- Electron focused, but in close contact to others creating other benchmarks
- Key4hep based to compare different full detector simulation and reconstruction chains

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Summary

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Plans:

- "Hardware": study optimisation of material budget and single-point resolutions
- Software: improve electron reconstruction
- Enable better and easier comparisons between concepts for future detectors!

This work has been sponsored by the Wolfgang Gentner Programme of the German Federal Ministry of Education and Research (grant no. 13E18CHA).

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References

[1] N. Bacchetta et al. *CLD – A Detector Concept for the FCC-ee*. 2019. arXiv: 1911.12230 [physics.ins-det].

[2] C. Grojean. "FCC physics case: the once, the now and the future". In: *FCC Week 2022*. 2022. URL: https://indico.cern.ch/event/1064327/contributions/4893259/.

[3] Jacqueline Yan et al. "Measurement of the Higgs boson mass and $e^+e^- \rightarrow ZH$ cross section using $Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$ at the ILC". In: *Phys. Rev. D* 94.11 (2016). [Erratum: Phys.Rev.D 103, 099903 (2021)], p. 113002. DOI: 10.1103/PhysRevD.94.113002. arXiv: 1604.07524 [hep-ex].

[4] E. Auffray. "Scintillating sampling ECAL technology for the Upgrade II of LHCb". In: *CALOR 2020*. 2022. URL: https://indico.cern.ch/event/847884/contributions/4833006/.

[5] M. Doser. *Quantum detectors for (low and high energy) particle physics*. 2022. URL: https://indico.cern.ch/event/1152324/.

Backup Slides

DetectorModels

- CLD Software based on Key4hep: All software available on Key4hep CVMFS
  `source /cvmfs/sw.hsf.org/key4hep/setup.sh`
  - DD4hep detector models
    - **FCCee_o1_v04 (k4geo)**: detector model used for most of the performance note [1]
    - **FCCee_o2_v01 (k4geo)**: detector model with updated beam pipe/VXD radii (10 mm)
    - **FCCee_o2_v02 (FCCDetectors)**:

Ideas for Further Studies I

Vertex detector and flavour tagging:

- Study implications of cooling needs at FCC-ee due to absence of power pulsing $\rightarrow$ so far only rough estimate of additional material
- Optimisation of the vertex detector for the Z pole (backgrounds, lower jet energies)
- Improved treatment of material in the vertex detector region (in particular cooled beam pipe)
- Investigate potential of PID in the flavour tagging (together with physics performance)

Tracking:

- Study implications of cooling needs at FCC-ee due to absence of power pulsing $\rightarrow$ so far only rough estimate of additional material
- Further optimisation of the tracker configuration $\rightarrow$ e.g., overall size and trade-off between more material from additional layers and better acceptance for long-lived particles
- Explore compatibility of alternative options (e.g., gaseous tracking) with the presence of beam-induced background

Ideas for Further Studies II

Precise timing capabilities:

- Potential of timing information with O(few ns) precision to reject particles from beam-induced background (including backscattered fragments)
- Impact of very precise timing information with O(few 10 ps) precision for PID $\rightarrow$ comparison of different approaches (ECAL or dedicated timing layer, maybe complemented by time information from tracking layers)

Further PID issues:

- Investigate if dE/dx from (thin) tracking layers can be useful
- Add RICH detector

Readout considerations:

- Further studies of detector integration times
- More detailed look at data rates and the possible need for a trigger

Calibration:

- Impact of calibration issues and the resulting systematic uncertainties with an emphasis on issues at the Z pole for which full simulation is needed (together with physics perf.) $\rightarrow$ e.g. uncertainties of various potential luminosity measurements, calibration of the b-tagging and c-tagging efficiencies and fake rates

Ideas for Further Studies III

Calorimetry:

- Study implications of cooling needs at FCC-ee due to absence of power pulsing $\rightarrow$ additional space needed / impact on sampling fractions
- Impact of full beam-induced background in the forward direction at the Z pole
- Explore if alternative technology options are compatible with PFA calorimetry and can provide better resolution for single EM particles $\rightarrow$ currently limited by Si-W ECAL
  - Scintillating sampling ECAL technology [4]
  - Or for the more speculative approach: Chromatic calorimetry with *Quantum Dots* [5]?

Luminosity detectors:

- Further background studies
- Inclusion of the MDI region and in particular the luminosity detectors in the CLD simulation