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

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CERN

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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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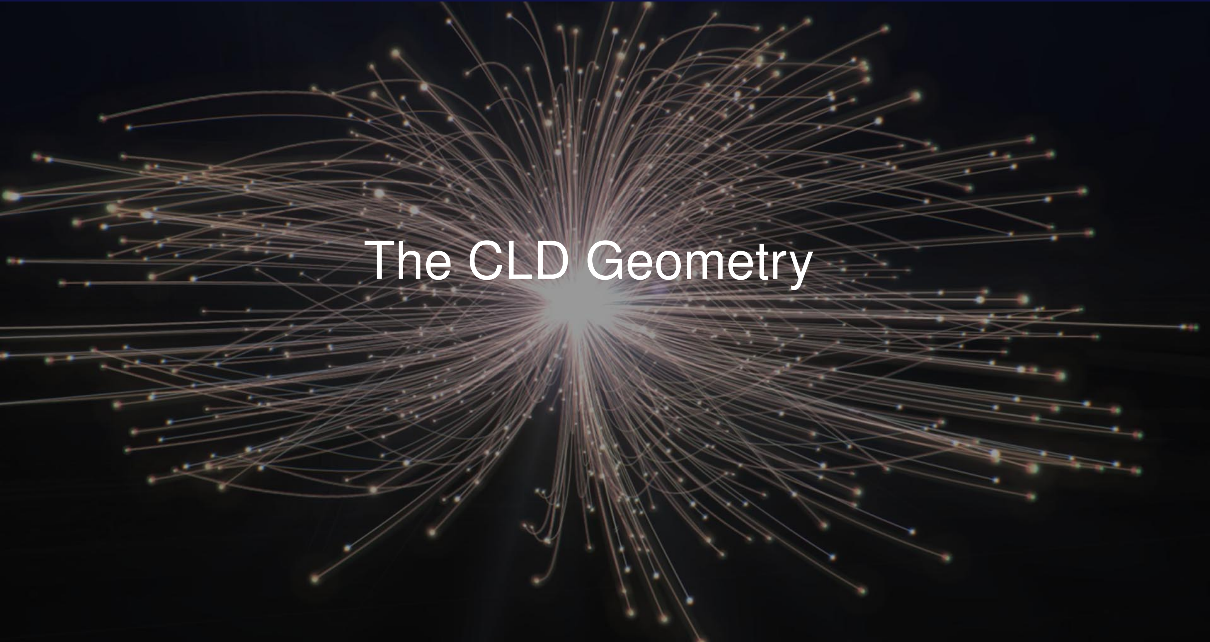
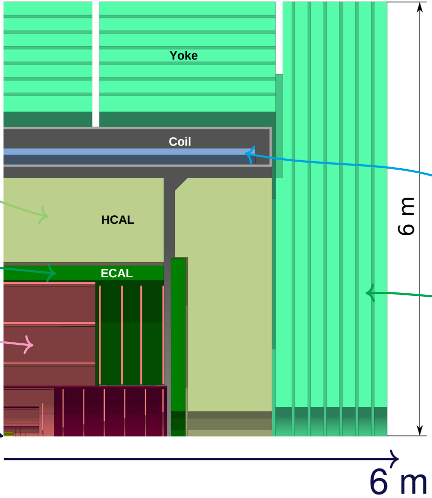
The CLD Geometry



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

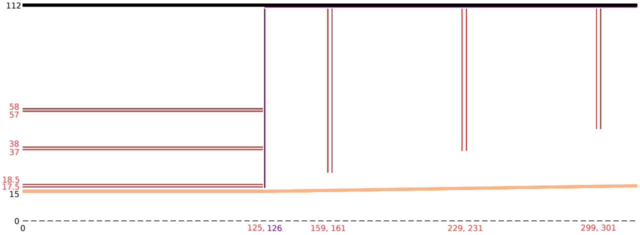


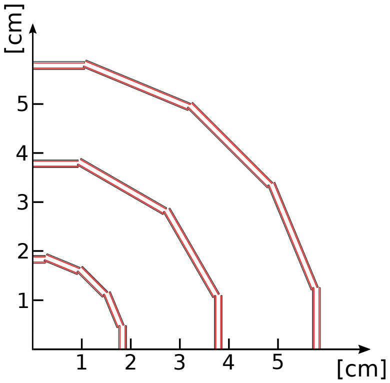
- Superconducting Solenoid of 2 T
- Iron Yoke with RPCs for Muon ID

Vertex Detector

FCCee_o1_v04

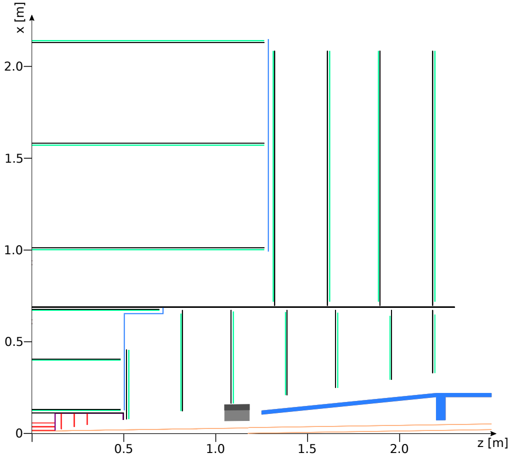
- Silicon vertex detector: precise vertex reconstruction
- 25×25 μm^2 pixels, 3 μm single point resolution
- 50 μm silicon thickness (+235 μm support etc.)
- Double layers (0.3%X_0 per detection layer)
- $R_{in} = 17.5$ mm (old beampipe)





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 × 0.3 mm cell size, 7 μm × 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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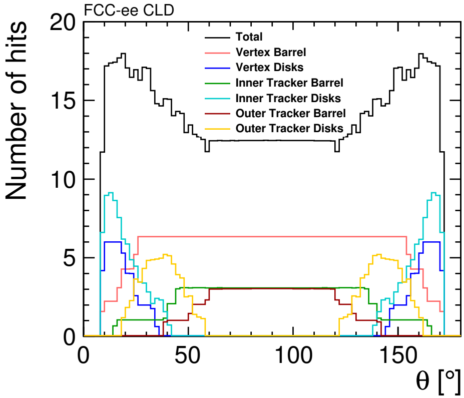

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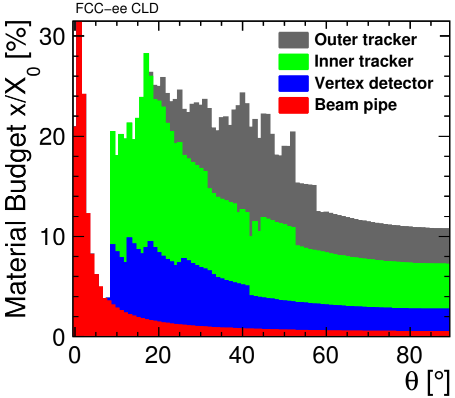
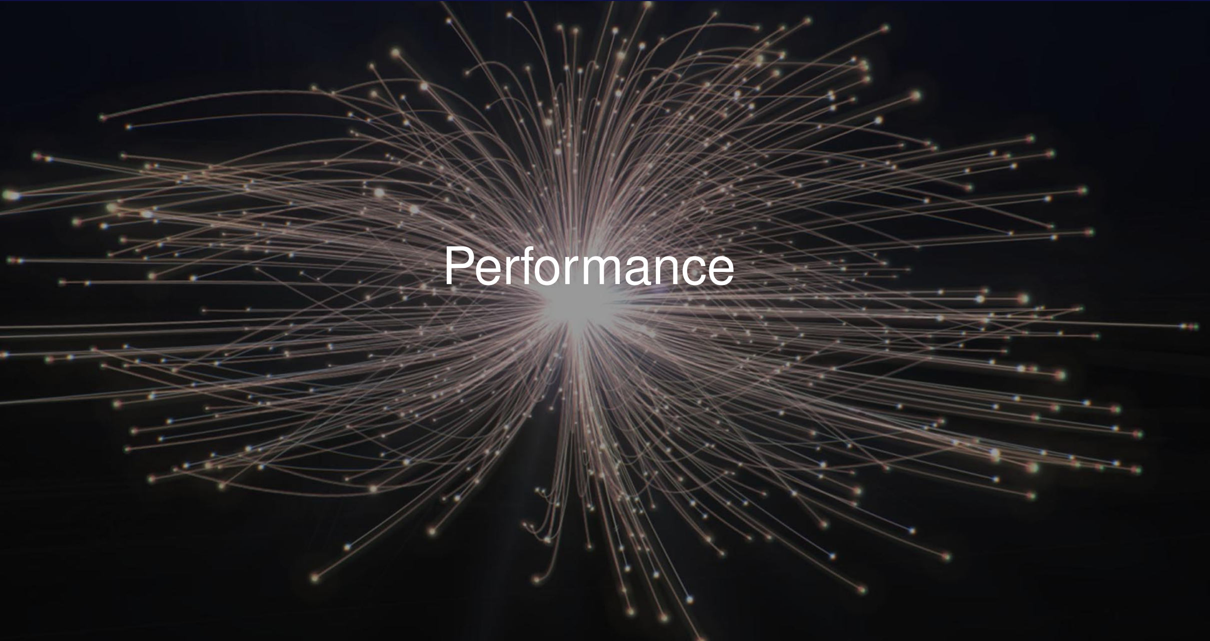


Performance



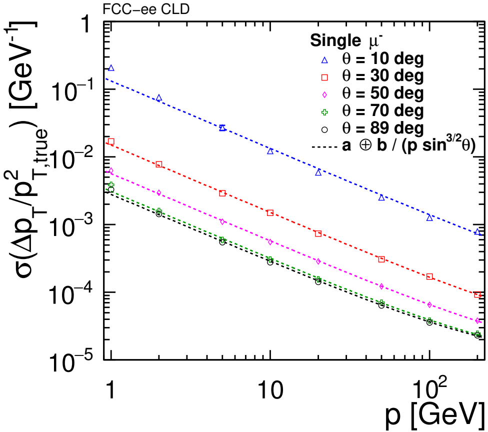
Performance Requirements and Studies

- 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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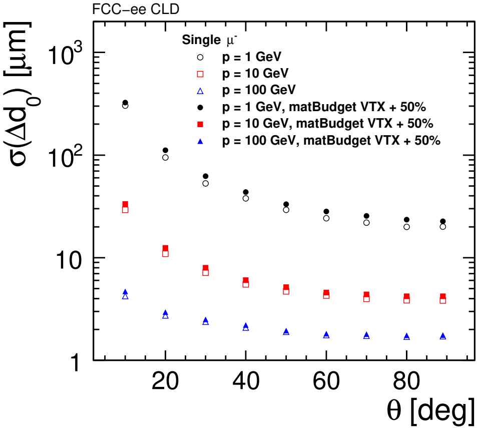

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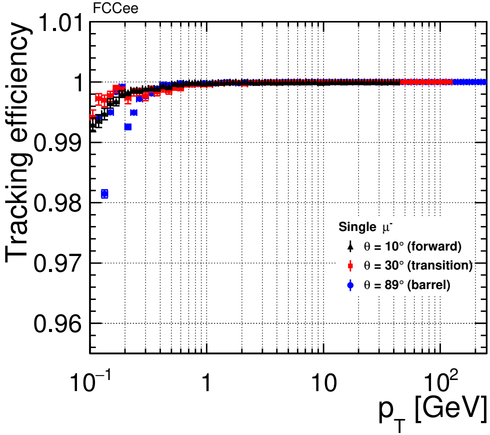

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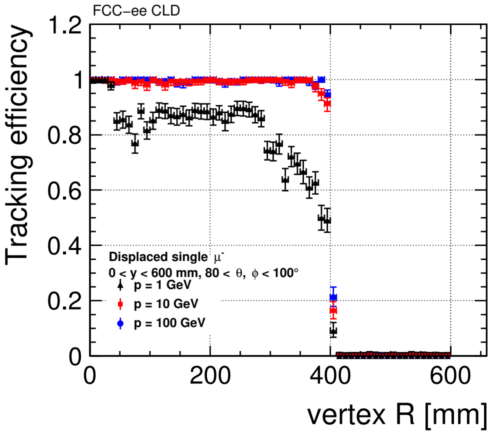

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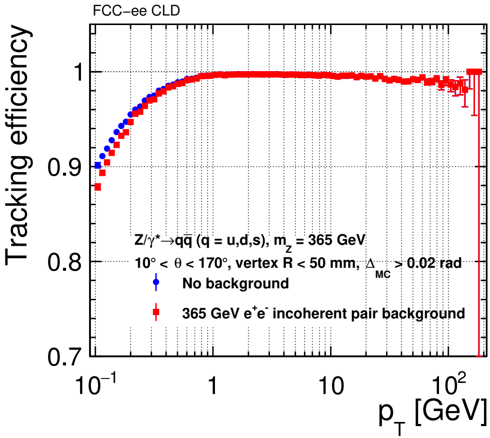

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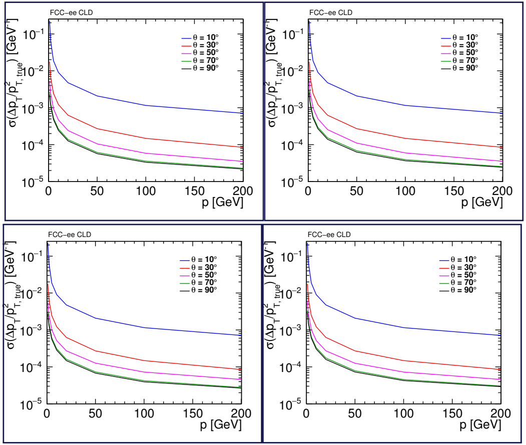
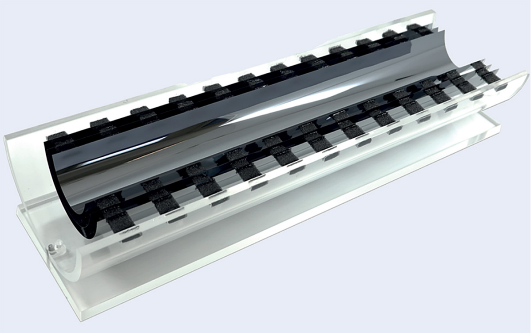


Optimisation Plans

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

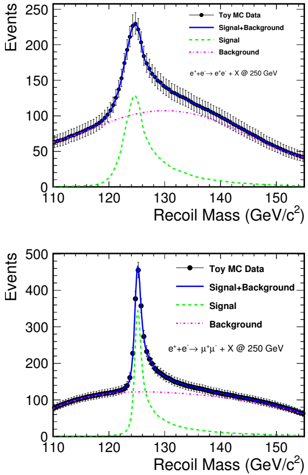


Inspiration?

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!

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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 $e^+e^- \to ZH$ cross section using $Z \to \mu^+\mu^-$ and $Z \to e^+e^-$ 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/.

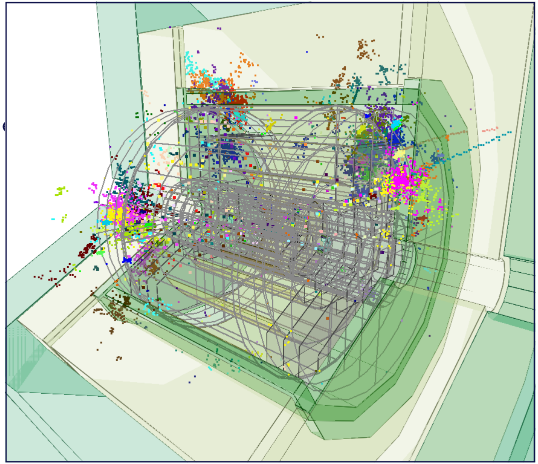
Backup Slides

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)**:

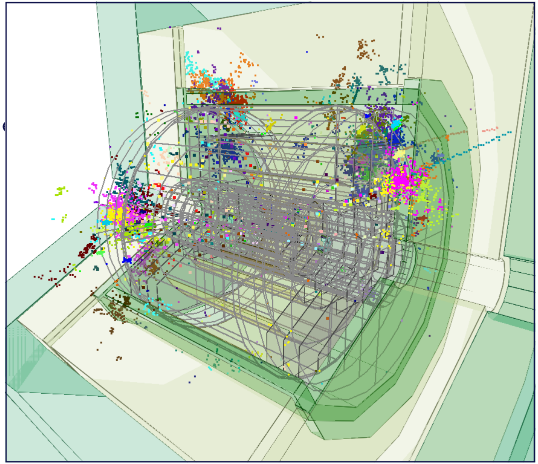
Event Display

- ced2go -d $LCGEO/FCCee/compact/FCCee_o2_v01/FCCe -v CEDViewer sim.slcio



Event Display

- `ced2go -d $LCGEO/FCCee/compact/FCCee_o2_v01/FCCe` `-v CEDViewer sim.slcio`
- Needs simulation output in slcio format (`ddsim ... -O sim.slcio ... `)
- `ced2go` is a wrapper around Marlin running a `CEDViewer` processor, so in principle we should be able to use this event display via `k4MarlinWrapper` and `EDM4hep` as well. . .



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 → 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.) → 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