

The CLD Detector Concept

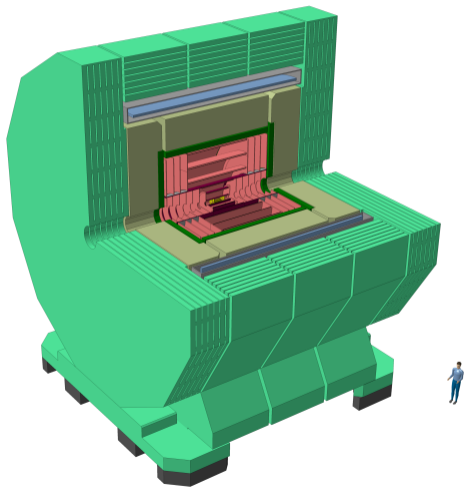
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CERN

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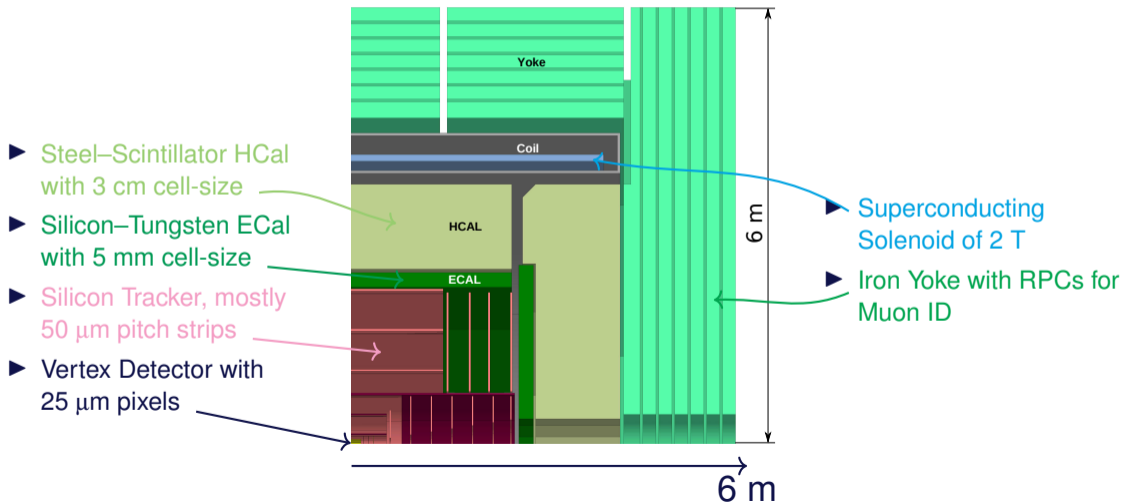




The CLD Geometry

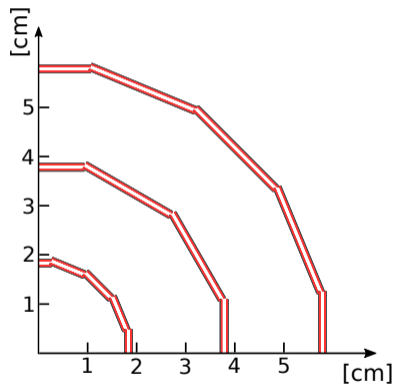
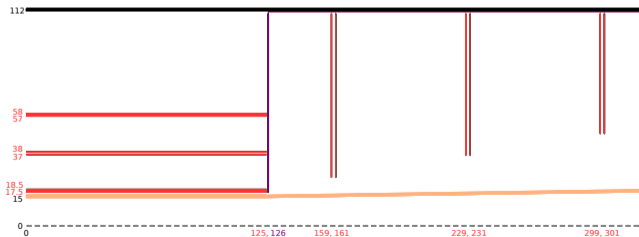
Detector for FCCee

General purpose detector for Particle Flow reconstruction [1]



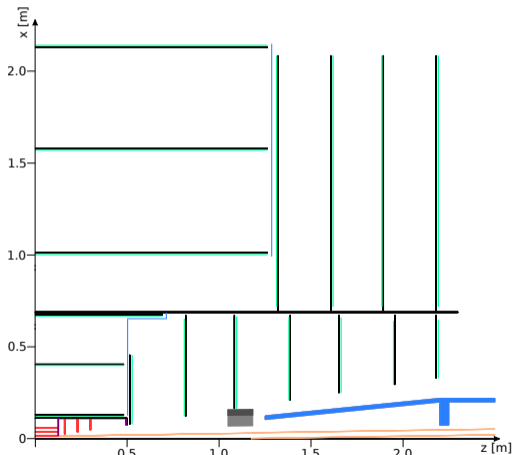
Vertex Detector

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



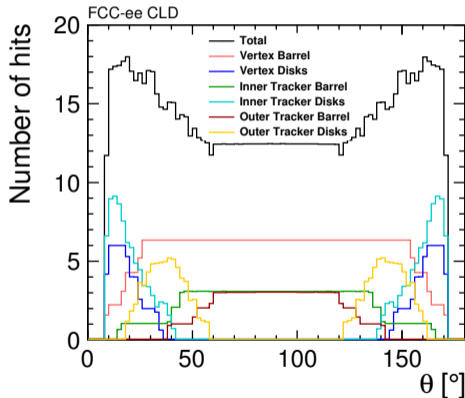
Silicon Tracking

- ▶ 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 $\mu\text{m} \times 0.3 \text{ mm}$ cell size, 7 $\mu\text{m} \times 90 \mu\text{m}$ single point resolution (except first inner tracker disk, 5 \times 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 [1]



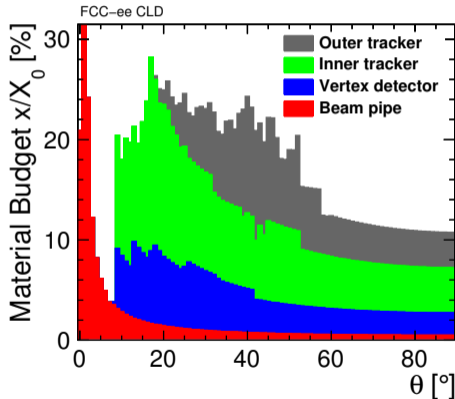
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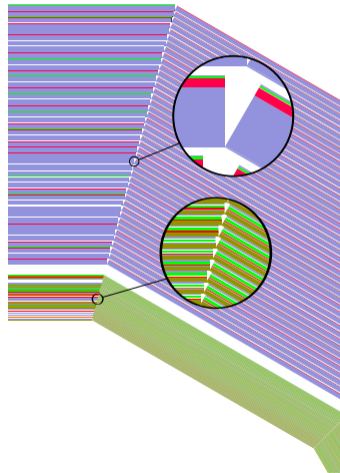
Calorimeters

ECal

- ▶ 40 layers, 1.9 mm tungsten absorber, $22 X_0$
- ▶ 0.5 mm thick silicon sensors with $5 \times 5 \text{ mm}^2$ granularity
- ▶ ECal optimisation studies [1, 2]

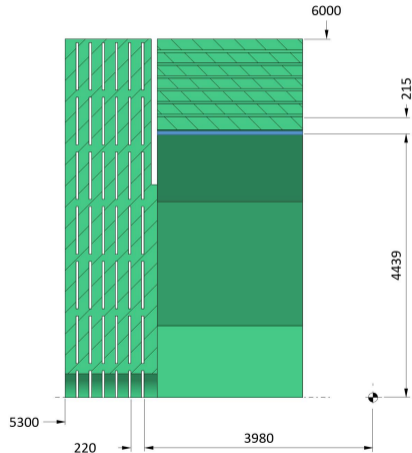
HCal

- ▶ 44 layers, 19 mm steel absorber, $5.5 (+1) \lambda_I$
- ▶ 3 mm thick scintillator tiles with $3 \times 3 \text{ cm}^2$ granularity



Magnet and Muon System

- ▶ 2 Tesla Solenoid Field
- ▶ Return yoke contains Muon system with 6 equidistant layers
 - ▶ One additional layer after the solenoid to serve as a *tail-catcher*





Performance

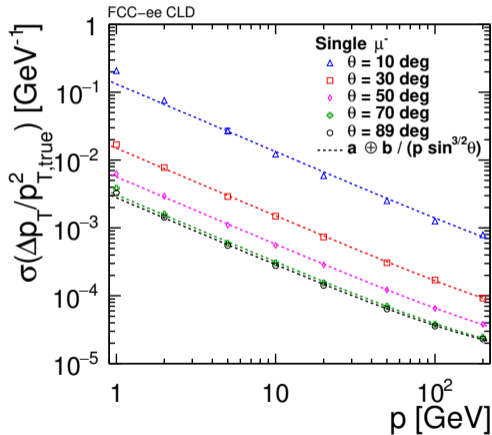
Performance Requirements and Studies

- ▶ Performance of CLD detector detailed in the note [1]
- ▶ Requirements for FCC detector [3]

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

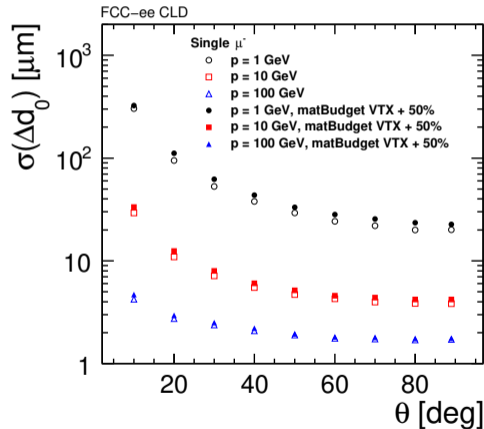
Tracking

- ▶ 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:
 $R_{\max} \in (2.1, 2.0, 1.9, 1.8) \text{ m}$



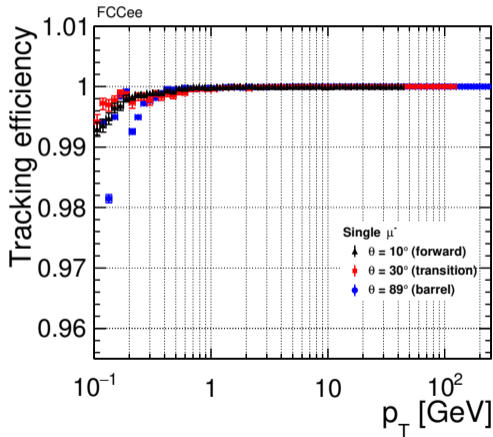
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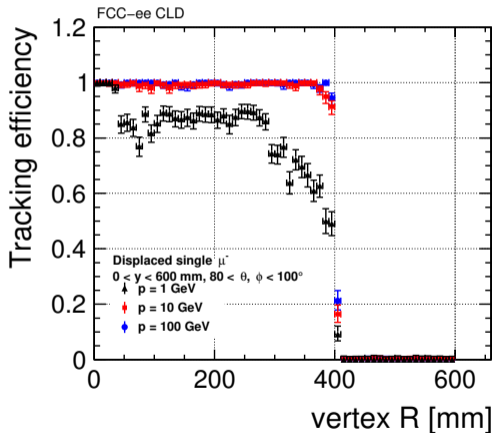
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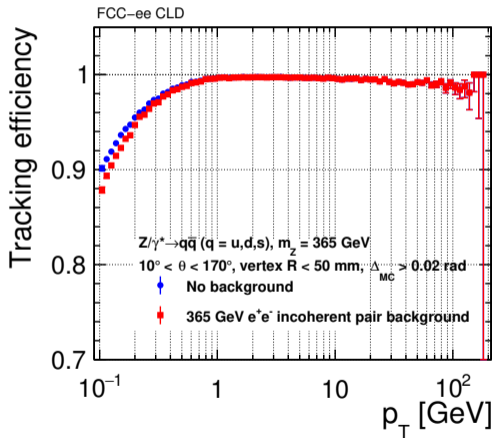
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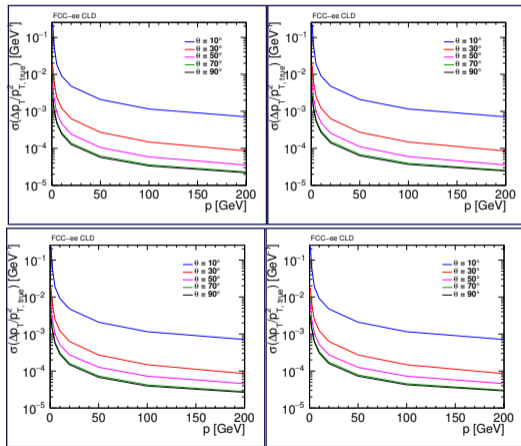
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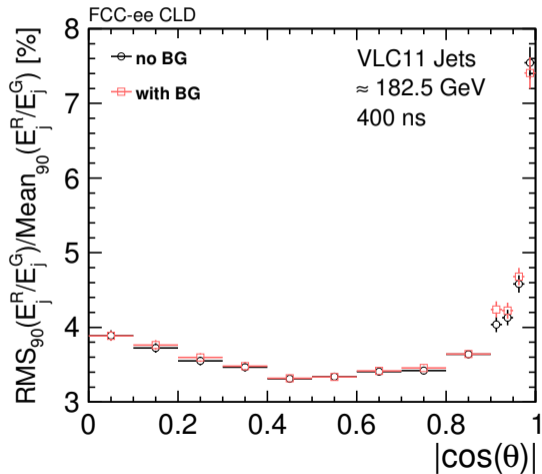
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Jets

Examples

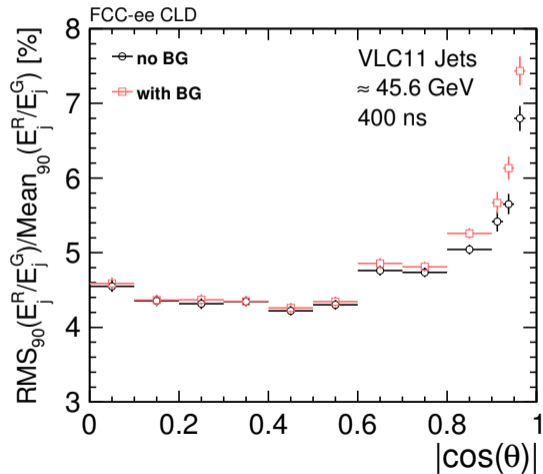
- ▶ Jet energy resolution including incoherent pair backgrounds
- ▶ Boson separation power
- ▶ Flavour Tagging



Jets

Examples

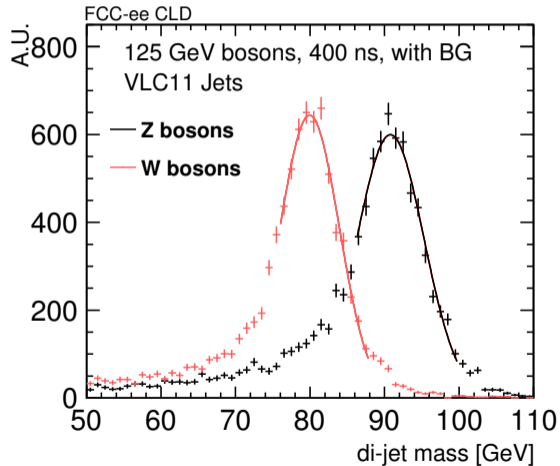
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Jets

Examples

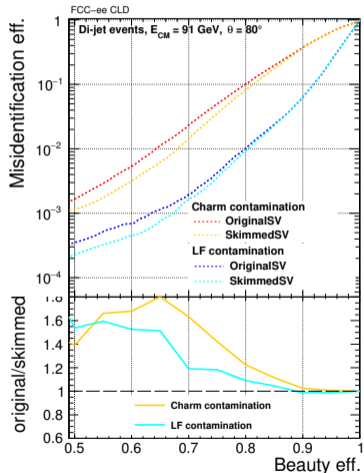
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- ▶ **Boson separation power**
- ▶ Flavour Tagging



Jets

Examples

- ▶ Jet energy resolution including incoherent pair backgrounds
- ▶ Boson separation power
- ▶ **Flavour Tagging**
 - ▶ Improving BTag performance by ignoring secondary vertices from material





Software

Key4hep Software

- ▶ Software for CLD part of the Key4hep software stack
- ▶ Available on CVMFS: `/cvmfs/sw.hsf.org/key4hep/setup.sh`
- ▶ Documentation: <https://key4hep.web.cern.ch>
- ▶ See also [presentation by V. Volkl](#)

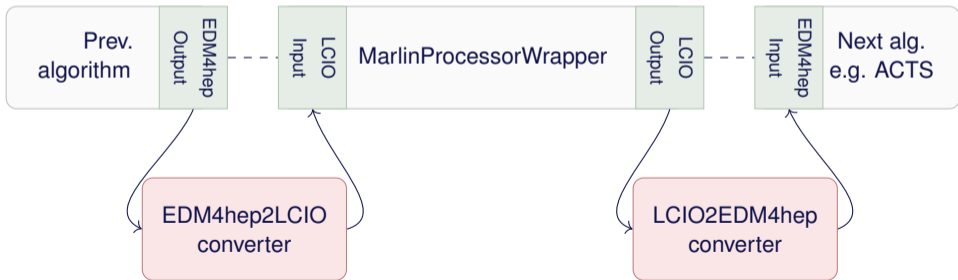
Full Simulation with DDSim

- ▶ Using `ddsim` and the CLD specific steering file
 - ▶ 30 mrad crossing angle
 - ▶ configuration of sensitive detectors, particularly Scintillator HCal (Birks' Law), and silicon tracking sensors
 - ▶ Physics list, simulation parameters (e.g., stepper, range cut)

```
source /cvmfs/sw.hsf.org/key4hep/setup.sh
git clone https://github.com/iLCSoft/CLICPerformance
cd CLICPerformance/fcceeConfig/
ddsim --compactFile $LCGEO/FCCee/compact/FCCee_o2_v01/FCCee_o2_v01.xml \
      --inputFiles ../Tests/yyxyev_000.stdhep \
      --numberOfEvents 3 \
      --steeringFile fcc_steer.py \
      --outputFile tops_edm4hep.root
```

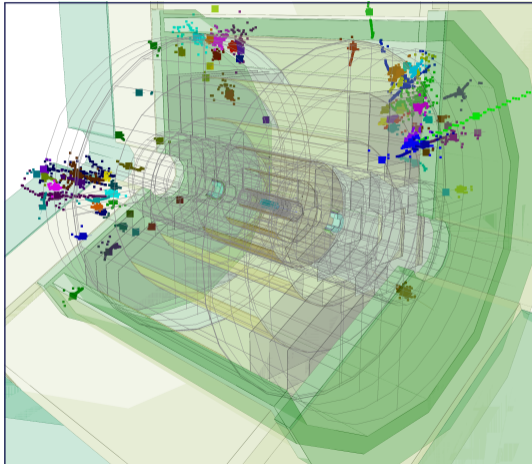
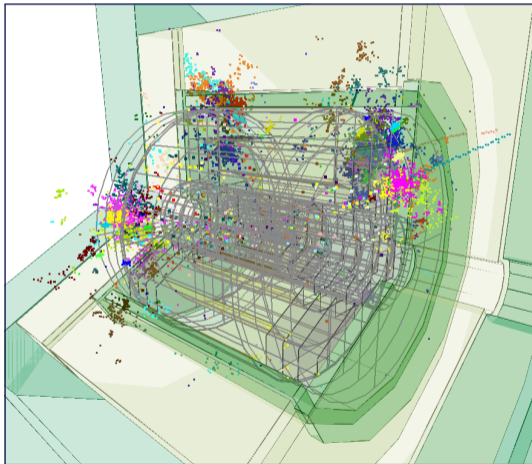
Reconstruction

- ▶ Reconstruction, consisting of,
 - ▶ Background Overlay, Digitisation
 - ▶ Track Pattern Recognition (ConformalTracking [4]), track fit
 - ▶ Particle Flow Reconstruction (PandoraPFA [5])
 - ▶ Vertexing and Flavour Tagging (LCFIplus [6])
- ▶ Run with Gaudi via the k4MarlinWrapper: `k4run fccRec_e4h_input.py`
 - ▶ Input and output in EDM4hep



*`wget https://raw.githubusercontent.com/key4hep/k4MarlinWrapper/master/test/gaudi_opts/fccRec_e4h_input.py`

Event Displays





Ideas for Further Studies

Ideas for Further Studies I

Vertex detector and flavour tagging:

- ▶ Study implications of **cooling needs** at FCC-ee due to **absence of power pulsing** → 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** → so far only rough estimate of additional material
- ▶ Further **optimisation** of the tracker **configuration** → 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

Calorimetry:

- ▶ Study implications of **cooling needs** at FCC-ee due to **absence of power pulsing** → 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 → currently limited by Si-W ECAL
 - ▶ Scintillating sampling ECAL technology [7]
 - ▶ Or for the more speculative approach: **Chromatic** calorimetry with *Quantum Dots* [8]?

Luminosity detectors:

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

Ideas for Further Studies III

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



Summary

Summary

- ▶ CLD detector model implemented for **full simulation and reconstruction**
 - ▶ Initial focus was on 250 GeV and above
- ▶ Many interesting **opportunities** for improvements and detailed studies
 - ▶ Software developments in Key4hep
 - ▶ Geometry and detector technology optimisation
 - ▶ Physics studies

References

- [1] N. Bacchetta et al. *CLD – A Detector Concept for the FCC-ee*. 2019. arXiv: 1911.12230 [physics.ins-det].
- [2] O. Viazlo and A. Sailer. “Efficient Iterative Calibration on the Grid using iLCDIrac”. In: *EPJ Web Conf.* 245 (2020), p. 03003. DOI: 10.1051/epjconf/202024503003.
- [3] 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/>.
- [4] E. Brondolin et al. “Conformal tracking for all-silicon trackers at future electron–positron colliders”. In: *Nucl. Instrum. Meth.* A956 (2020), p. 163304. ISSN: 0168-9002. DOI: <https://doi.org/10.1016/j.nima.2019.163304>.
- [5] J.S. Marshall and M.A. Thomson. “The Pandora Software Development Kit for Pattern Recognition”. In: *Eur.Phys.J.* C75.9 (2015), p. 439. DOI: 10.1140/epjc/s10052-015-3659-3.
- [6] T. Suehara and T. Tanabe. “LCFIPlus: A Framework for Jet Analysis in Linear Collider Studies”. In: *Nucl. Instrum. Meth.* A808 (2016), pp. 109–116. DOI: 10.1016/j.nima.2015.11.054.
- [7] 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/>.
- [8] M. Doser. *Quantum detectors for (low and high energy) particle physics*. 2022. URL: <https://indico.cern.ch/event/1152324/>.



Thank you for your attention



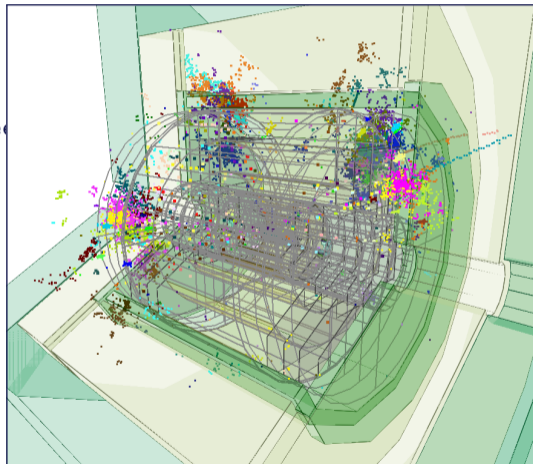
Backup Slides

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 \(lcgeo\)](#): detector model used for most of the performance note [1]
 - ▶ [FCCee_o2_v01 \(lcgeo\)](#): detector model with updated beam pipe/VXD radii (10 mm)
 - ▶ [FCCee_o2_v02 \(FCCDetectors\)](#):

Event Display

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



Event Display

- ▶ `ced2go -d`
`$LCGEO/FCCee/compact/FCCee_o2_v01/FCCee`
`-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...

