CLD: A Detector Model for the FCC-ee

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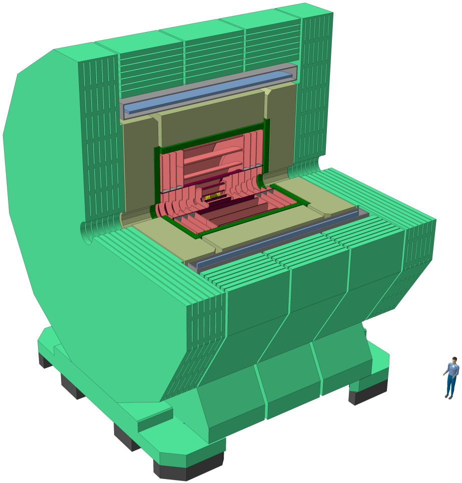


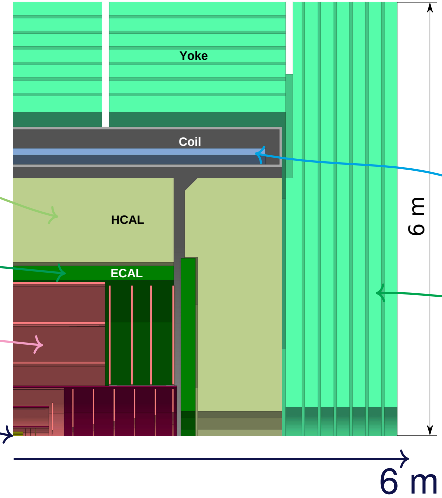
Section 1:

- The CLD Detector Model(s)

The CLD Detector Model

General purpose detector for Particle Flow reconstruction [1]

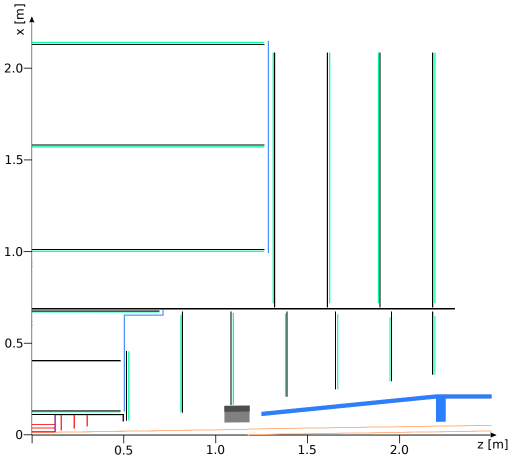
- Steel–Scintillator HCal with 3 cm cell-size
- Silicon–Tungsten ECal with 5 mm cell-size
- Silicon Tracker, mostly 50 μm pitch strips
- Vertex Detector with 25 μm pixels



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

Silicon Tracker

- 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 [1]



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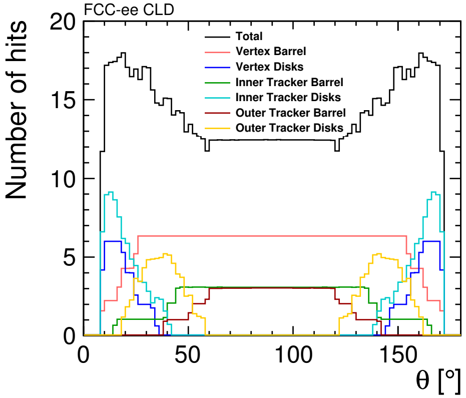

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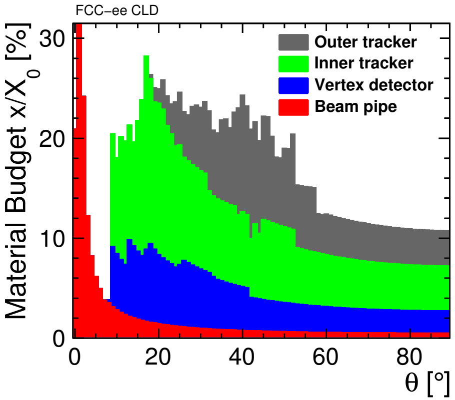
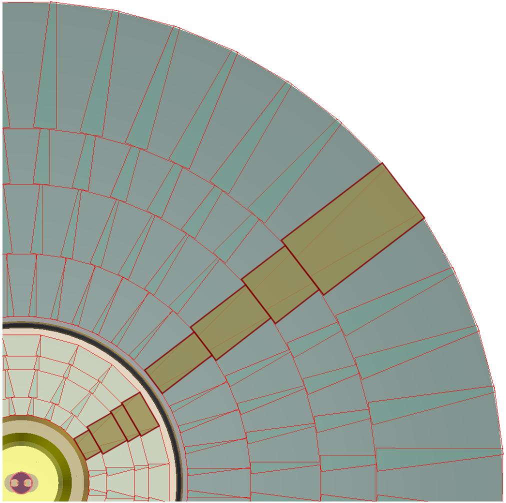


Silicon Modules

- Silicon tracker made up of $15.1 \times 15.1\ mm^2$ and $30.1 \times 30.1\ mm^2$ pieces
- Integer number of pieces put together to create modules, modules repeated to form disks
- This limits the sensible places were to place modules to avoid gaps
- Re-structuring needs careful placements or changes in quantum numbers



Flavours

All versions of the CLD detector model now reside in **k4geo**, any others must not be used

- FCCee_o1_v05: original base, large beam pipe radius
- CLD_o2_v05: Latest baseline
- CLD_o3_v01: Inclusion of ARC for PID, reduced tracker dimensions
- CLD_o4_v05: Replace ECal barrel with LAr, increased HCal/Coil/Muon dimensions

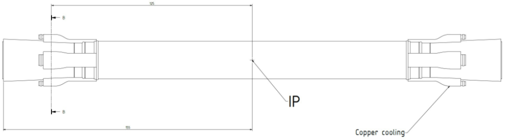
CLD_02_v05

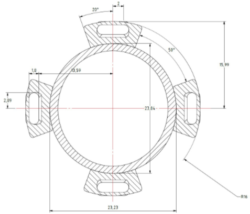
- Modifications for the vertex detector to fit with the new design for the innermost beampipe, including liquid cooling of the beampipe
- Fixed wrong number and size of modules in the last ring of the last inner tracker endcap
- Fixed some small overlaps
- Removed HOM (Higher-Order-Mode) absorber, which is no longer needed for low impedance beampipe

New Beampipe Dimensions

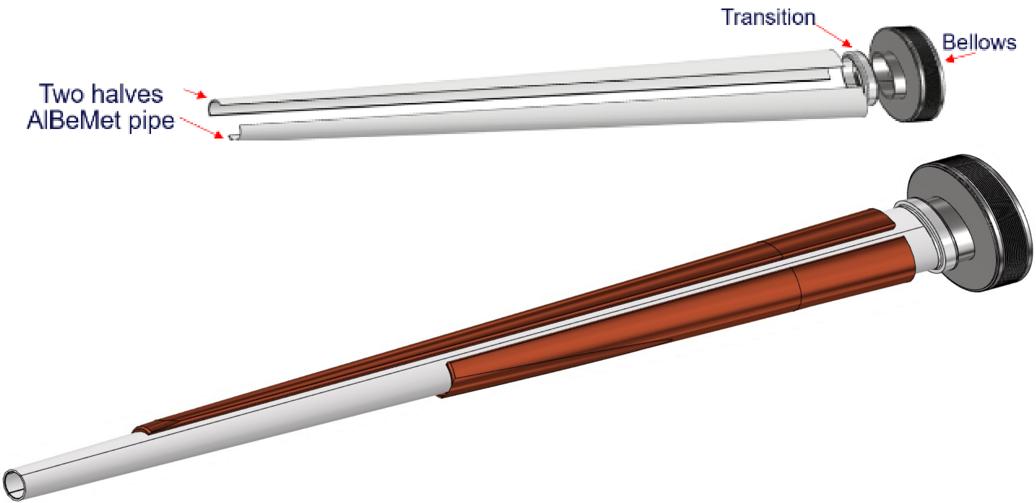
- New beam pipe design. Figures from [2]
- Liquid cooling for central cylinder (right side).
- Round to conical shape (see next slide), include shielding.
- For CLD_02_v05, only using primitive volumes available in Geant4 and TGeo, no CAD created pieces
  - Conical chamber is conical, no circular to ellipse volume available

[mm]	Cyl R_{min}	Cyl R_{max}	Cyl L	Cone R_{min}
v02	10	11.2	125	11
v05	**10**	**11.7**	**90**	**12**





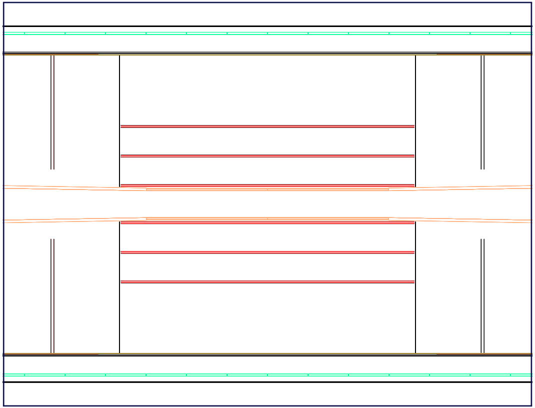
Beampipe Design [3]



Vertex Barrel Parameters

- Modified radius of first double layers and length of all ladders to fit with new beampipe dimensions
- Width and number of ladders the same.
- Slightly reduce number of hits in overlap with VTX endcaps
- Keep cylindrical support possibility

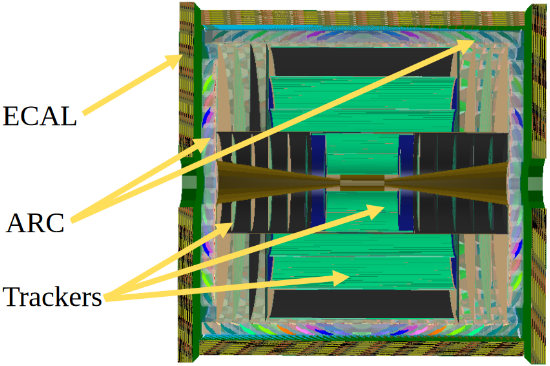
[mm]	R_1	R_2	R_3	L
v02	12.5	35	57	125
v05	**13.0**	**35**	**57**	**109**



Cut through the vertex detector around the interaction point

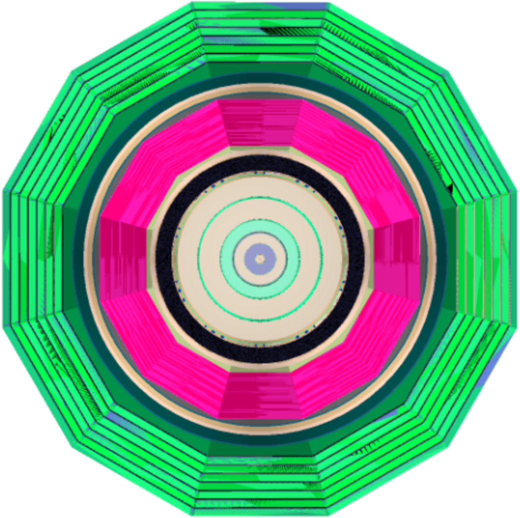
CLD_o3_v01

- ARC PID Detector implementation by A. Tolosa-Delgado
- Reduced tracker sizes to fit RICH cells before the ECal
- Need to finalise the tracker sizes, understand performance



CLD_o4_v05

- ECal Barrel replaced by LAr
- HCal, Solenoid, Yoke moved outwards by ≈40 cm
- Testing PandoraPFA for LAr, making interfaces more generic



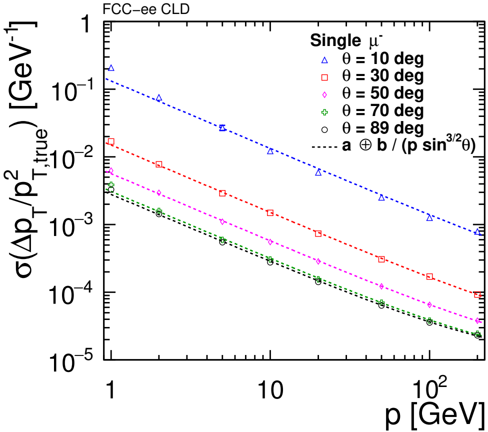
Performance Requirements and Studies

- Performance of CLD detector detailed in the note [1]
- Requirements for FCC detector [4]

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_\mathrm{T}) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_\mathrm{T} \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	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	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (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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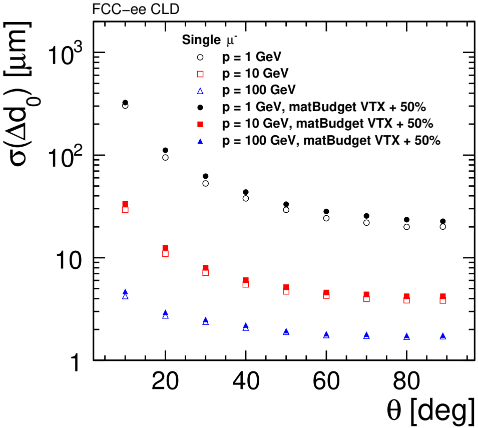

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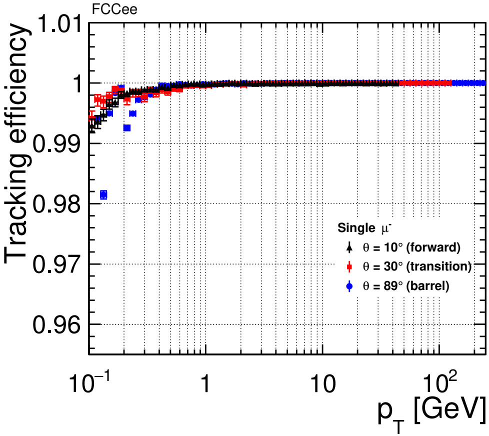

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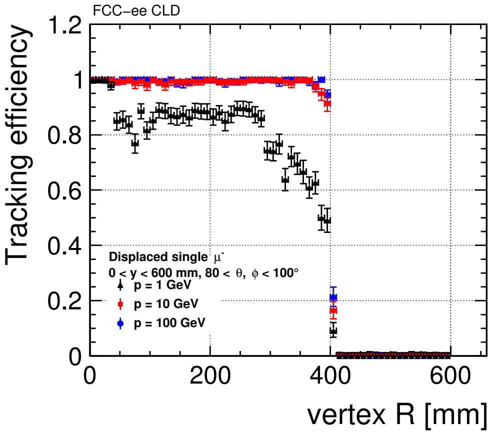

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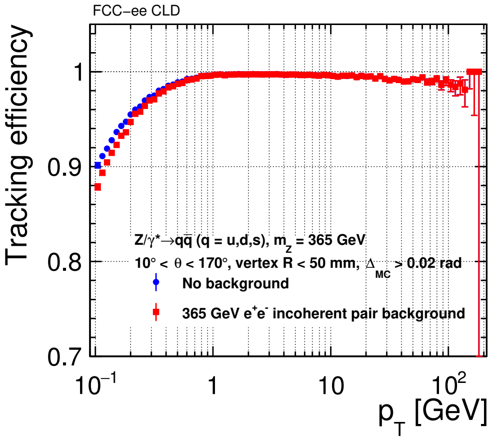

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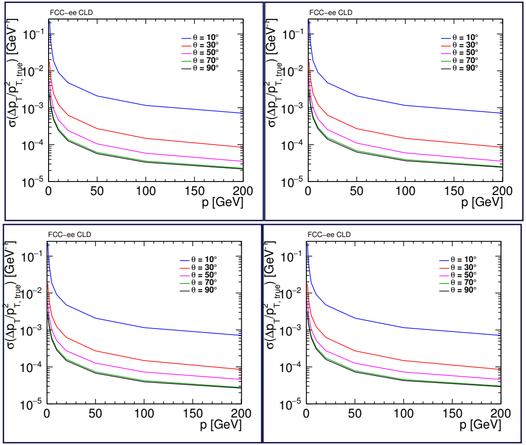
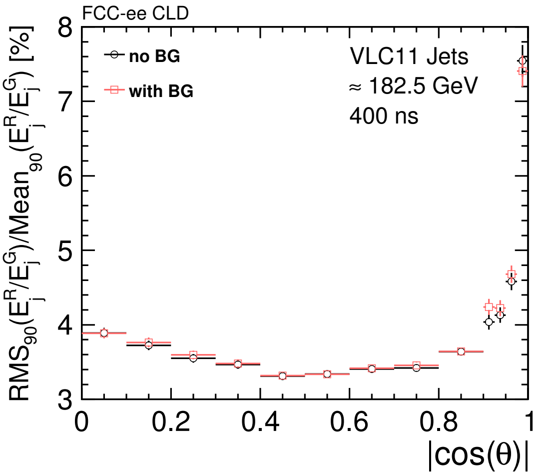


Jets

Examples

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



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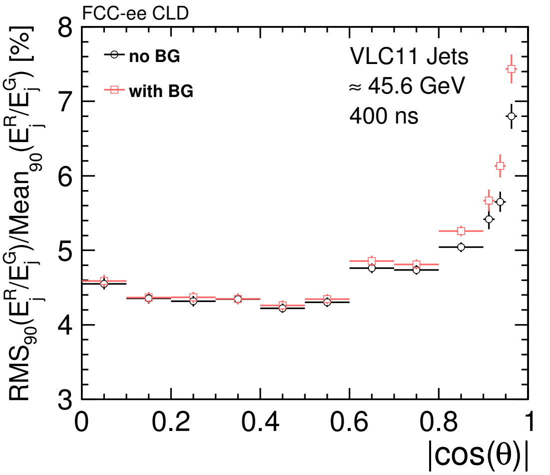

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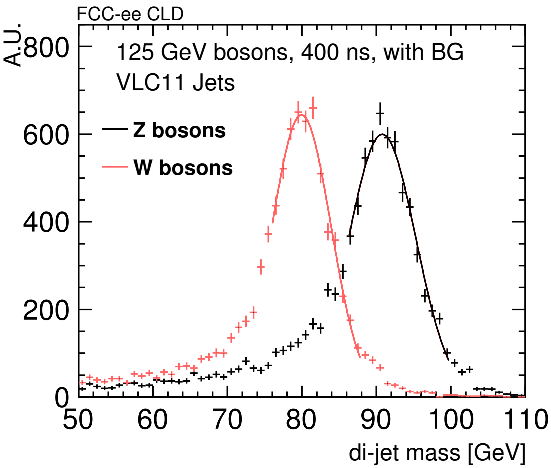

Jets

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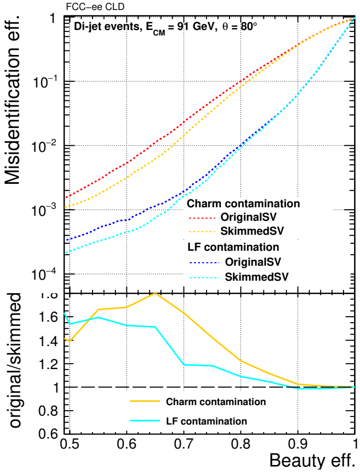
  - Improving BTag performance by ignoring secondary vertices from material

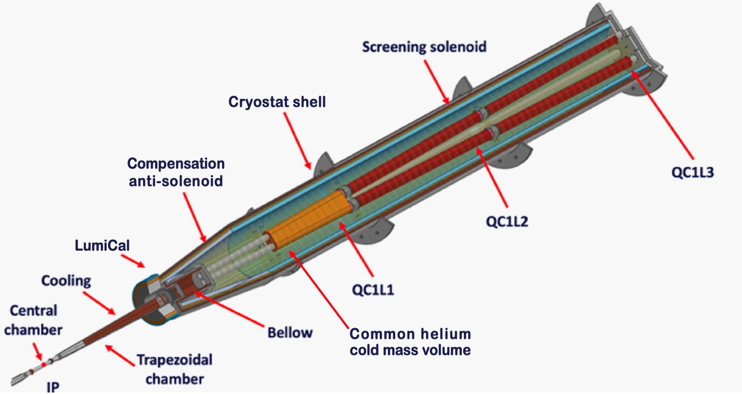


Section 2:

- FCCee Machine Detector Interface and Backgrounds

FCCee Machine Detector Interface and Backgrounds

- $L^{\star} = 2.2$ m
- LumiCal at $Z \approx 1$ m
- Figures from MDI Overview at FCC Week [3]



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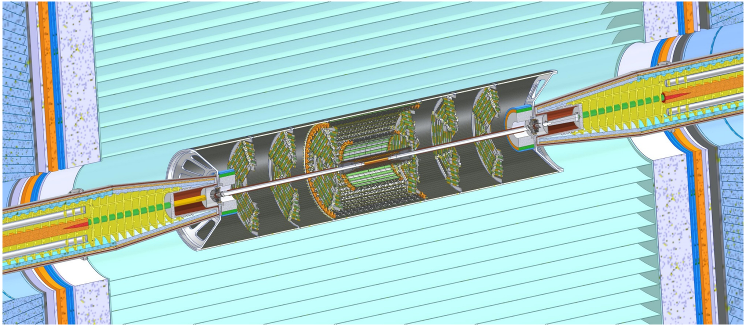
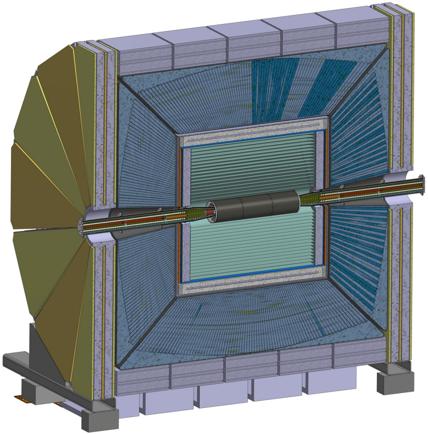
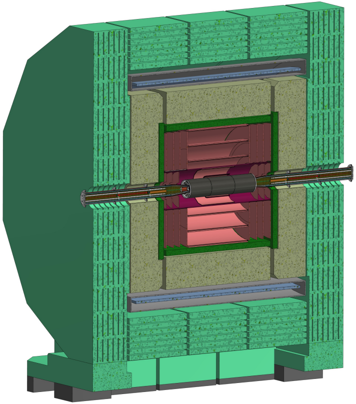


Common Insert for Detectors? [3]





Backgrounds

- Most up-to-date background studies by A Ciarma [5]
  - Incoherent Pairs, Radiative Bhabhas, Synchrotron Radiation
- So far no special mitigation for the detector required

Section 3:

- Software

Software

- The CLD detector model works with the Key4hep software stack
- *ddsim* for simulation
- Mostly Gaudi-Wrapped iLCSoft processors for reconstruction
- **github.com/Key4hep/CLDConfig**

References

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

[2] Manuela Boscolo, Fabrizio Palla, et al. “The FCC-ee interaction region, design and integration of the machine elements and detectors, machine induced backgrounds and key performance indicators (FCC note)”. In: (2023). DOI: 10.17181/w4kws-rne05. URL: https://new-cds.cern.ch/doi/10.17181/w4kws-rne05.

[3] Manuela Boscolo. “MDI Overview”. In: *FCC Week 2023*. 2023. URL: https://indico.cern.ch/event/1202105/contributions/5385348/.

[4] 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/.

[5] Andrea Ciarma and Manuela Boscolo. “Detector background simulations”. In: *FCC Week 2023*. 2023. URL: https://indico.cern.ch/event/1202105/contributions/5390909/.

Thank you for your attention