

Background Studies for the ILD Detector Concept at the FCC-ee

DPG Spring Meeting 2025

1st April 2025

Daniel Jeans (KEK), Jenny List,
Victor Schwan

victor.schwan@cern.ch

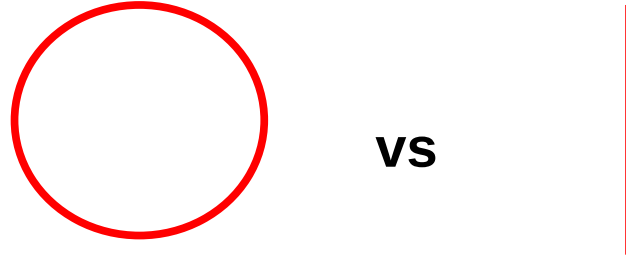
HELMHOLTZ



CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE



Background Studies for the ILD Detector Concept at the FCC-ee



HELMHOLTZ



CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

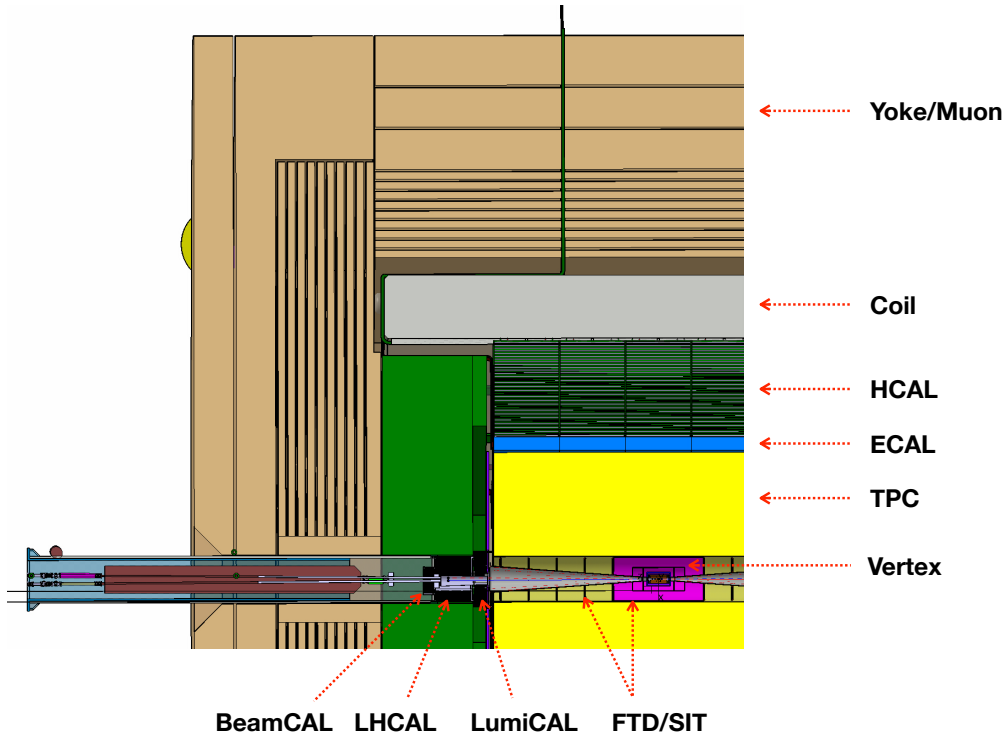


The International Large Detector (ILD) @ ILC*

- ❖ For an e^+e^- linear collider
- ❖ CoM energy range: 90 GeV – 1 TeV
- ❖ Multi-purpose detector
- ❖ Based on particle flow paradigm

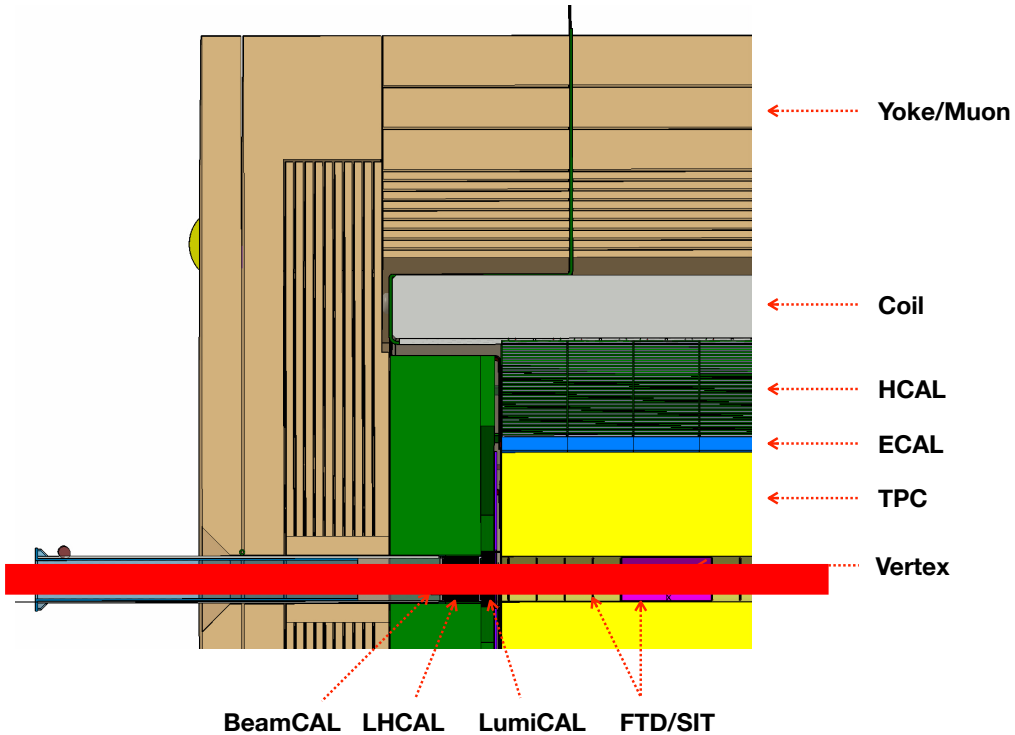
*International Linear Collider

The International Large Detector (ILD) @ ILC



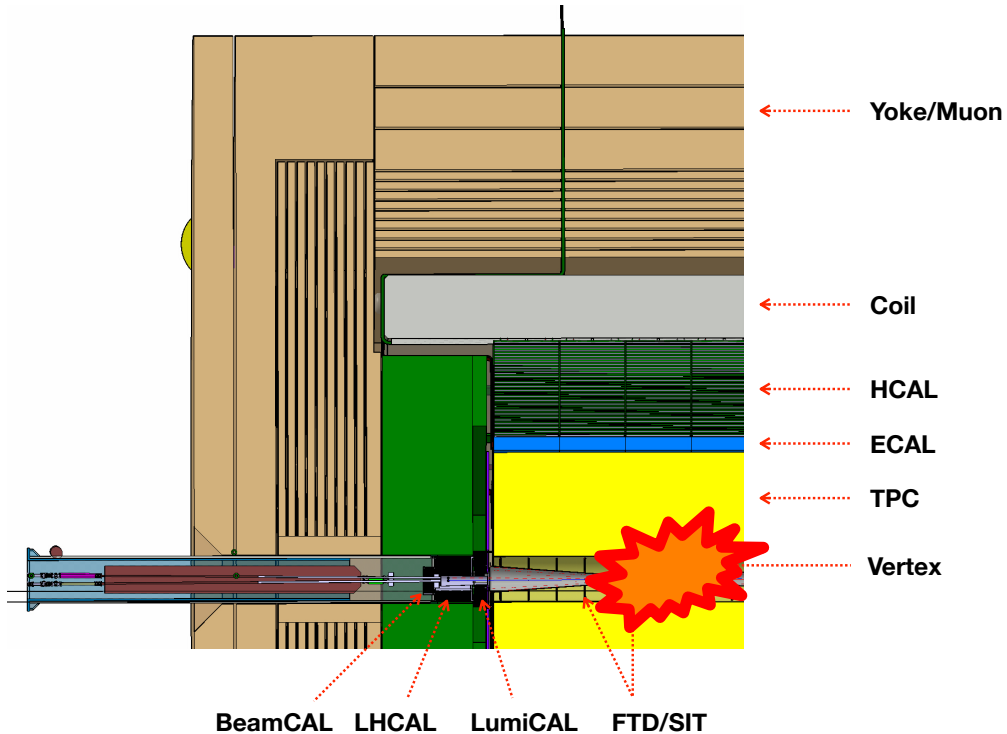
- ❖ For an e^+e^- linear collider
- ❖ CoM energy range: 90 GeV – 1 TeV
- ❖ Multi-purpose detector
- ❖ Based on particle flow paradigm

The International Large Detector (ILD) @ ILC



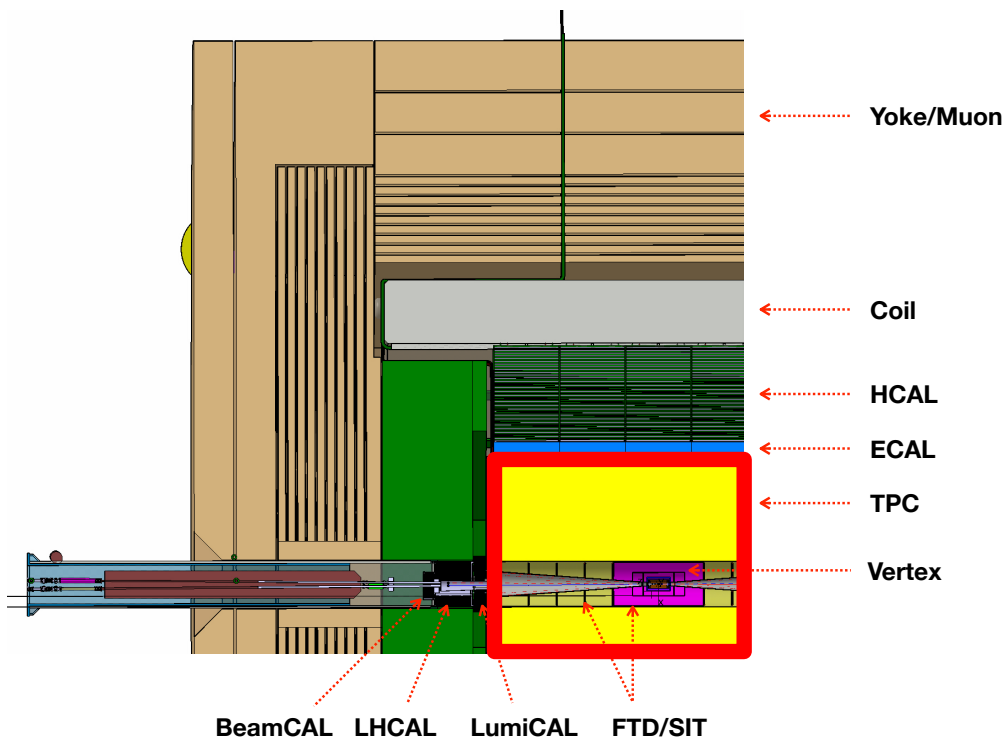
- ❖ For an e^+e^- linear collider
- ❖ CoM energy range: 90 GeV – 1 TeV
- ❖ Multi-purpose detector
- ❖ Based on particle flow paradigm

The International Large Detector (ILD) @ ILC



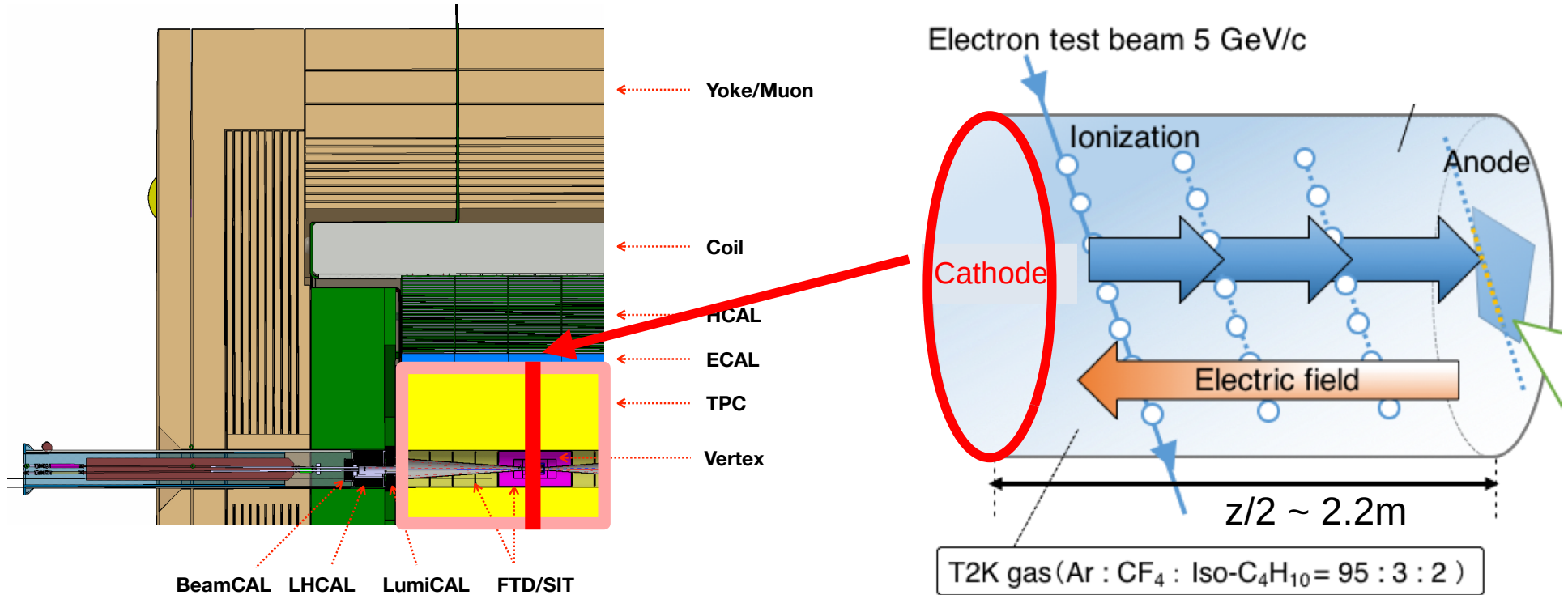
- ❖ For an e^+e^- linear collider
- ❖ CoM energy range: 90 GeV – 1 TeV
- ❖ Multi-purpose detector
- ❖ Based on particle flow paradigm

The International Large Detector (ILD) @ ILC



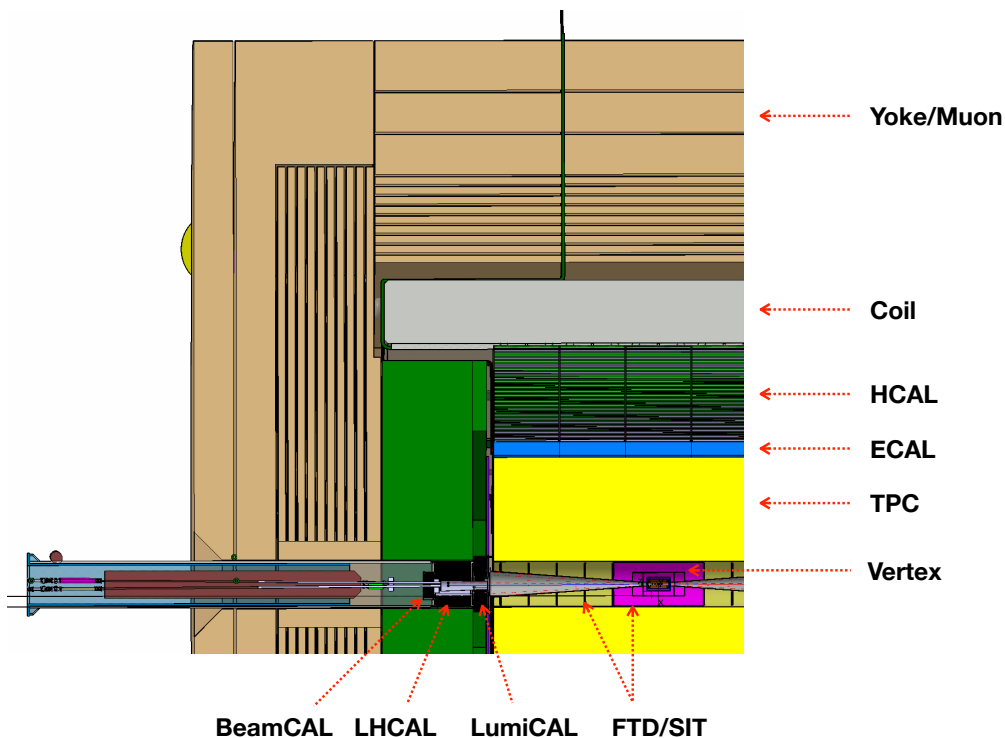
- ❖ For an e^+e^- linear collider
- ❖ CoM energy range: 90 GeV – 1 TeV
- ❖ Multi-purpose detector
- ❖ Based on particle flow paradigm
- ❖ Hybrid tracking system:
Silicon + large-volume time projection chamber (TPC)

The International Large Detector (ILD) @ ILC



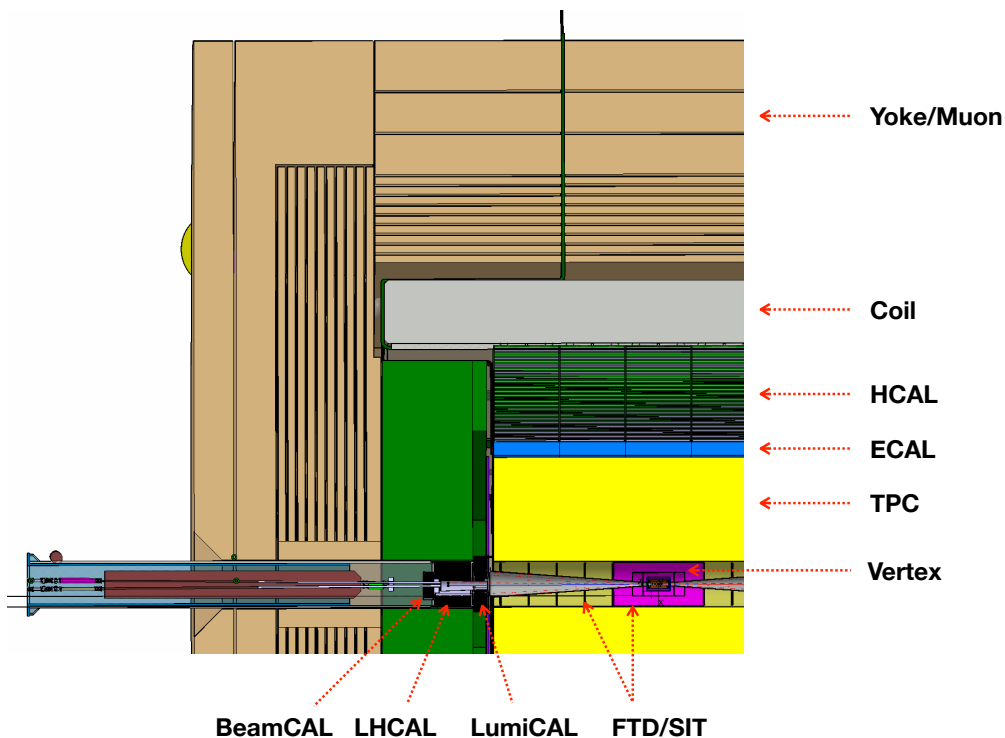
Graphic adapted from <https://doi.org/10.48550/arXiv.1801.04499>

The International Large Detector (ILD) @ ILC



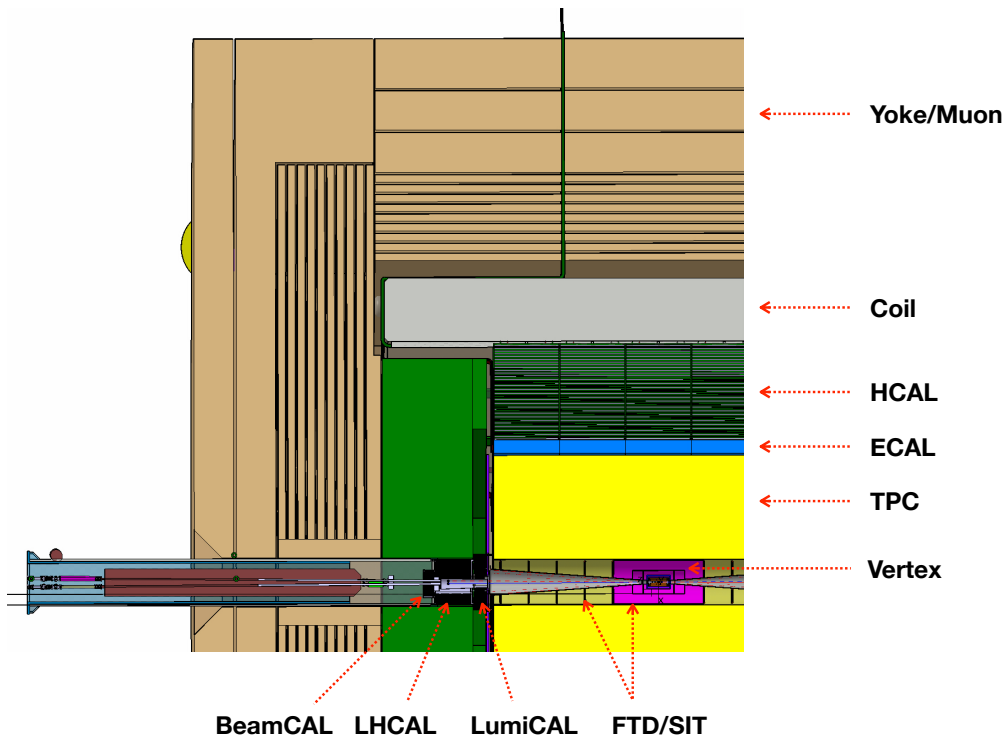
- ❖ For an e^+e^- linear collider
- ❖ CoM energy range: 90 GeV – 1 TeV
- ❖ Multi-purpose detector
- ❖ Based on particle flow paradigm
- ❖ Hybrid tracking system:
 - Silicon + large-volume time projection chamber (TPC)
 - ❖ Continuous 3-dim tracking
 - ❖ dE/dx -based particle identification (PID)
 - ❖ Minimal material

The International Large Detector (ILD) @ ILC



- ❖ For an e+e- linear collider
- ❖ CoM energy range: 90 GeV – 1 TeV
- ❖ Multi-purpose detector
- ❖ Based on particle flow paradigm
- ❖ Hybrid tracking system:
 - Silicon + large-volume time projection chamber (TPC)
 - ❖ Continuous 3-dim tracking
 - ❖ dE/dx-based particle identification (PID)
 - ❖ Minimal material
- ❖ Hermetic down to ~6mrad

The International Large Detector (ILD) @ ILC



- ❖ For an e^+e^- linear collider
- ❖ CoM energy range: 90 GeV – 1 TeV
- ❖ Multi-purpose detector
- ❖ Based on particle flow paradigm
- ❖ Hybrid tracking system:
 - Silicon + large-volume time projection chamber (TPC)
 - ❖ Continuous 3-dim tracking
 - ❖ dE/dx -based particle identification (PID)
 - ❖ Minimal material
- ❖ Hermetic down to $\sim 6\text{mrad}$

⇒ **Well-developed, optimized for Higgs / top / EW physics in 90 GeV to 1 TeV**

Effect of Background Processes on the TPC

Beam-Induced Backgrounds (BIBs)

1) Single-Beam:

- ❖ Synchrotron radiation (SR)

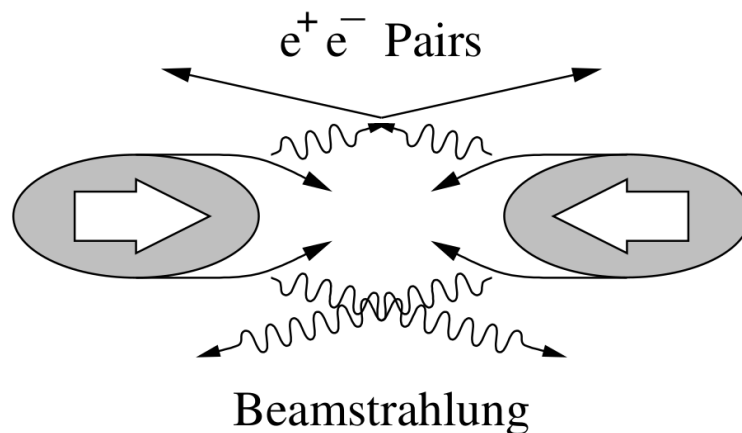
Beam-Induced Backgrounds (BIBs)

1) Single-Beam:

- ❖ Synchrotron radiation (SR)

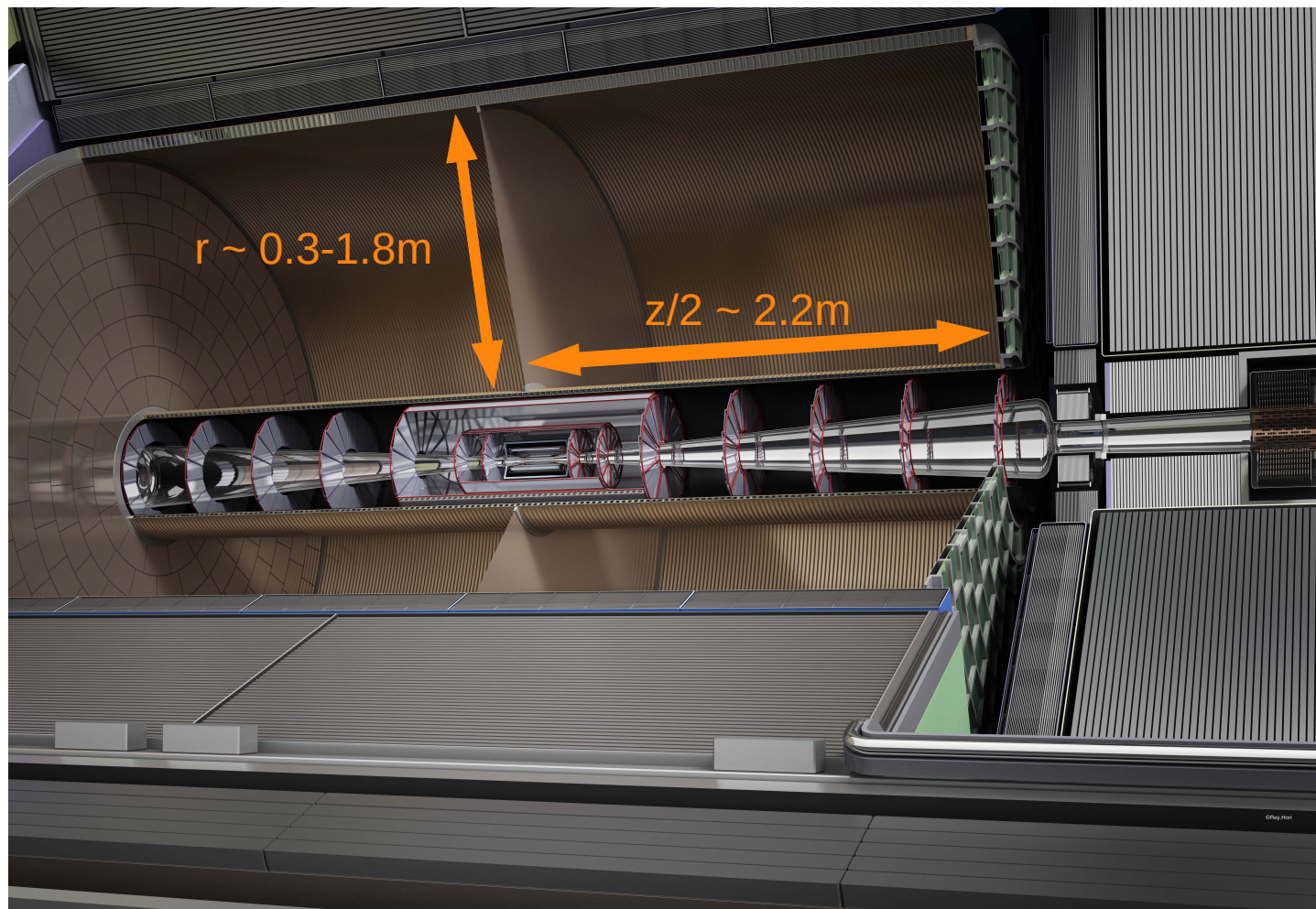
2) Beam-beam interaction:

- ❖ Beamstrahlung: SR emitted in the field of the oncoming bunch during collision
- ❖ Scales with luminosity



Effect of BIBs on TPC Operation

- ❖ Primary ions and ion backflow from gas amplifier (GEM, microMegas, ...)
- ❖ Ions build up in TPC volume due to slow drift speed
- ❖ Distort trajectory of ionization electrons
- ❖ May degrade momentum resolution
- ❖ Beamstrahlung expected to be major contributor



Number of Primary Ions Produced in TPC per BX

- ❖ Only ions originating from beamstrahlung considered
- ❖ a **few 100k** → **1M** primary ions / BX
- ❖ ILC and FCC-ee are similar

ILC vs FCC-ee: Beam Conditions

	ILC*	FCC-ee**	
Beam energy [GeV]	125	45.6	182.5
Luminosity / IP [$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$]	1.35	141	1.83
Polarization	e^+ : 80%, e^- : 30%	-	-
Pulse structure [length, rep. rate]	1 ms, 5 Hz	continuous	

* Interim Design Report 2020

** FCC-ee collider lattice version V23

Number of Primary Ions Produced with Collision Rate

❖ **TPC integrates over many collisions**; maximum ion drift time ~ 0.44 s

#ions $\approx$ primary ions/BX * BX freq * max drift time * 50%

[some ions already reached cathode]

Collider	FCC-91	FCC-240	ILC-250
Detector model	ILD_FCCee_v01	ILD_FCCee_v01	ILD_15_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	260 k	820 k	450 k
primary ions in TPC at any time	1.7×10^{12}	1.4×10^{11}	6.5×10^8
average primary ion charge density nC/m ³	6.4	0.54	0.0025

❖ Primary ion density in TPC:

D. Jeans

❖ **2500** times higher at FCC-ee-91 than ILC-250

❖ **200** times higher at FCC-ee-240 than ILC-250

❖ expected maximum distortion due to beamstrahlung at FCC-91 is O(cm) [primary ions only, ILD_FCCee_v01]

❖ Similar distortion in ALICE's TPC, uncertainties reduced by surrounding silicon tracker

Summary

- ❖ Propelling the decision and R&D for a future collider project is crucial
- ❖ ILD exemplifies a well-designed detector concept optimized for a broad Higgs / top / EW physics program from 90 GeV up to 1 TeV
- ❖ At FCC-ee 91 GeV, the TPC is the most challenging sub-detector to operate
- ❖ Primary ion density from beamstrahlung is substantially higher in the TPC at FCC-ee 91 GeV than at ILC
- ❖ Further studies on the adaption of ILD and the MDI necessary

FIN

Back-Up

ILC vs FCC-ee: Beam Conditions

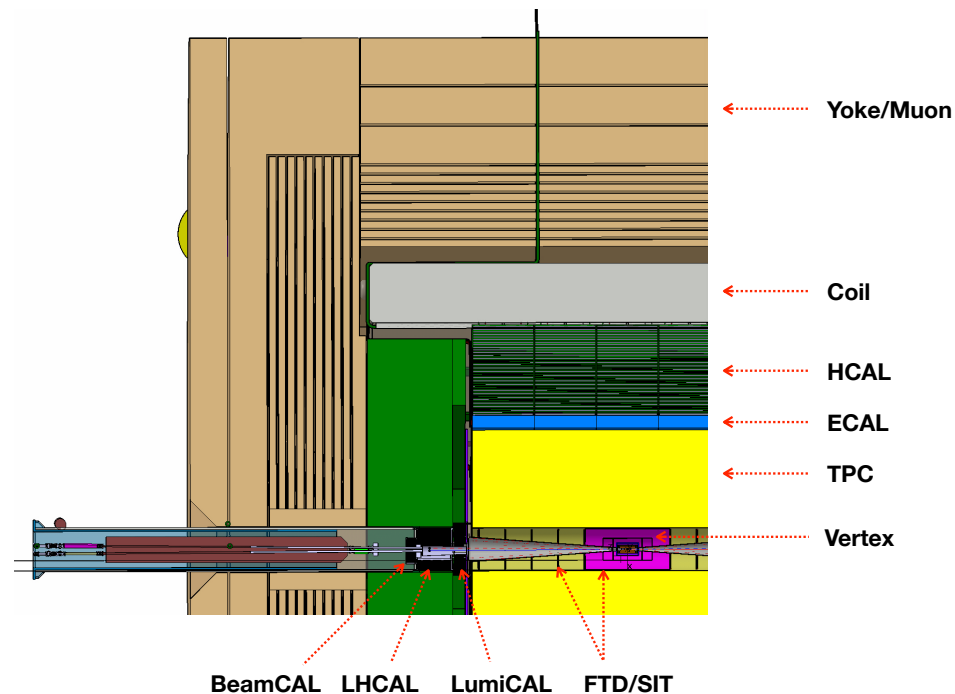
	ILC*	FCC-ee**	
Beam energy [GeV]	125	45.6	182.5
Luminosity / IP [$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$]	1.35	141	1.83
Polarization	e ⁺ : 80%, e ⁻ : 30%	-	-
Pulse structure [length, rep. rate]	1 ms, 5 Hz	continuous	
Crossing angle [mrad]	14	30	

* Interim Design Report 2020

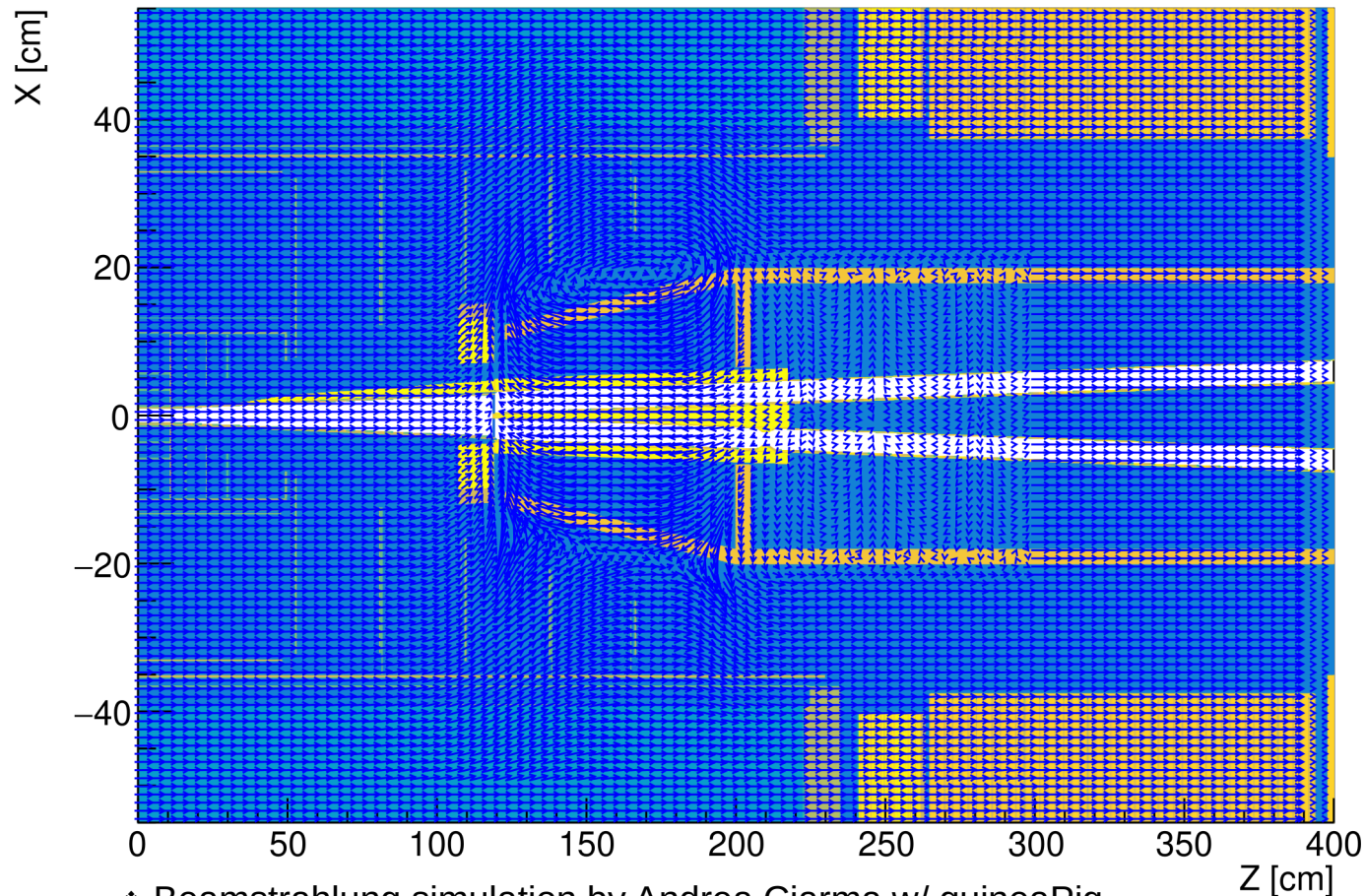
** FCC-ee collider lattice version V23

ILC vs FCC-ee: Machine-Detector Interface (MDI)

	ILC	FCC-ee
Crossing angle [mrad]	14	30
L^* [m]	4.1	2.2
Detector solenoid [T]	3.5	2
Additional B-fields	anti-DID	compensating + screening



Magnetic Field Map of ILD_FCCee_01



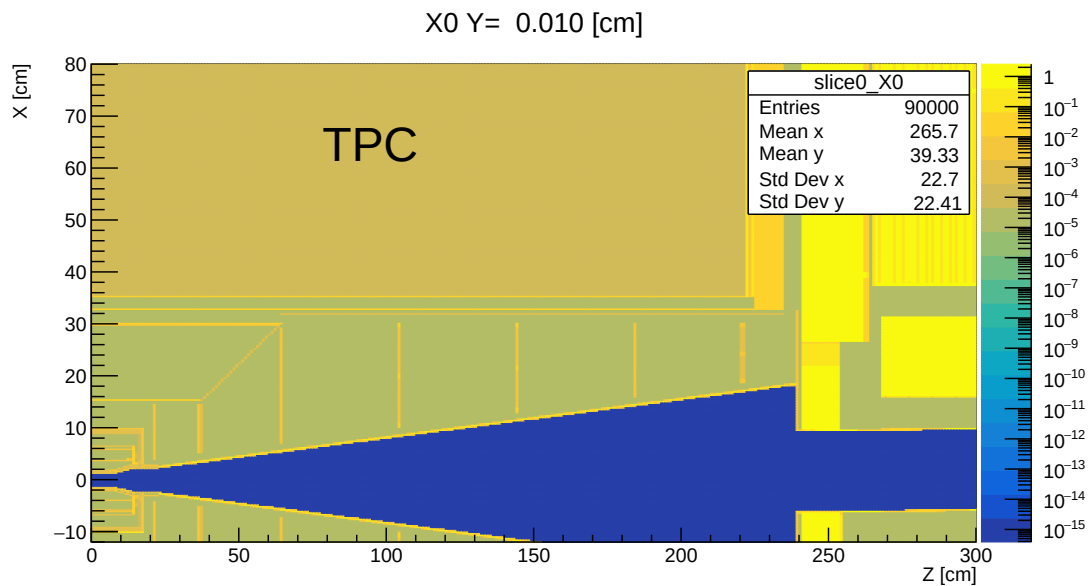
❖ Beamstrahlung simulation by Andrea Ciarma w/ guineaPig

❖ Only Vertex Detector considered, TPC results in detector parallel session by Daniel Jeans

Starting Point

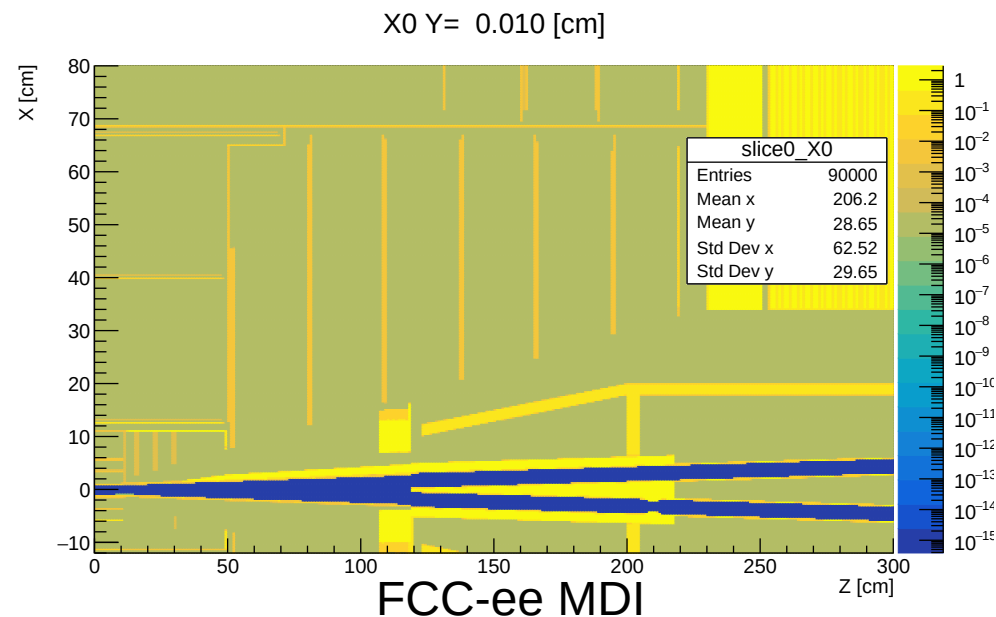
ILD (for ILC)

- ❖ ILC MDI
- ❖ Hybrid tracking layout



CLD (CLIC-like Detector)

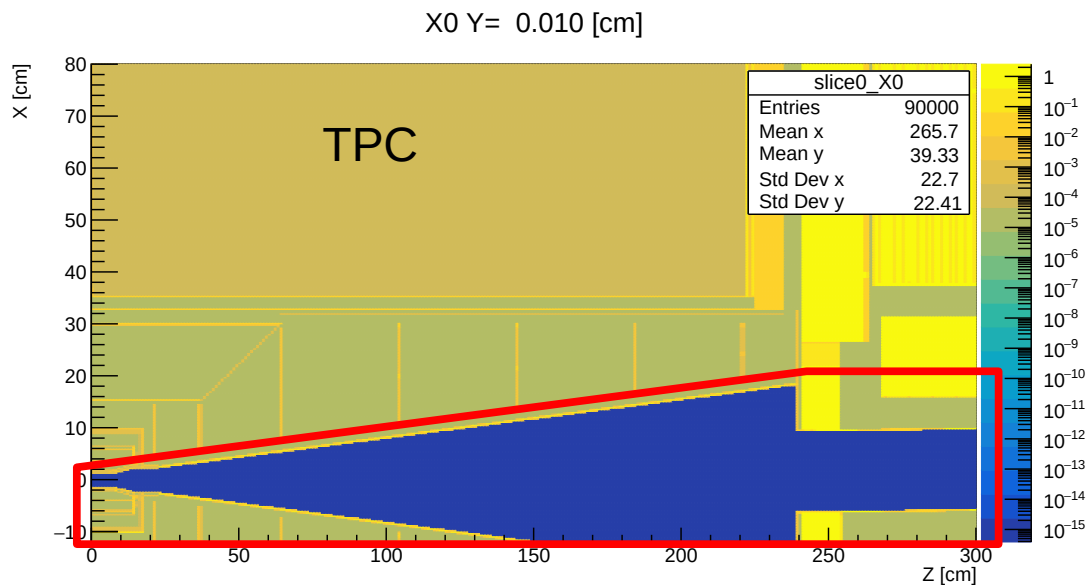
- ❖ FCC-ee MDI
- ❖ All-silicon tracking



Starting Point

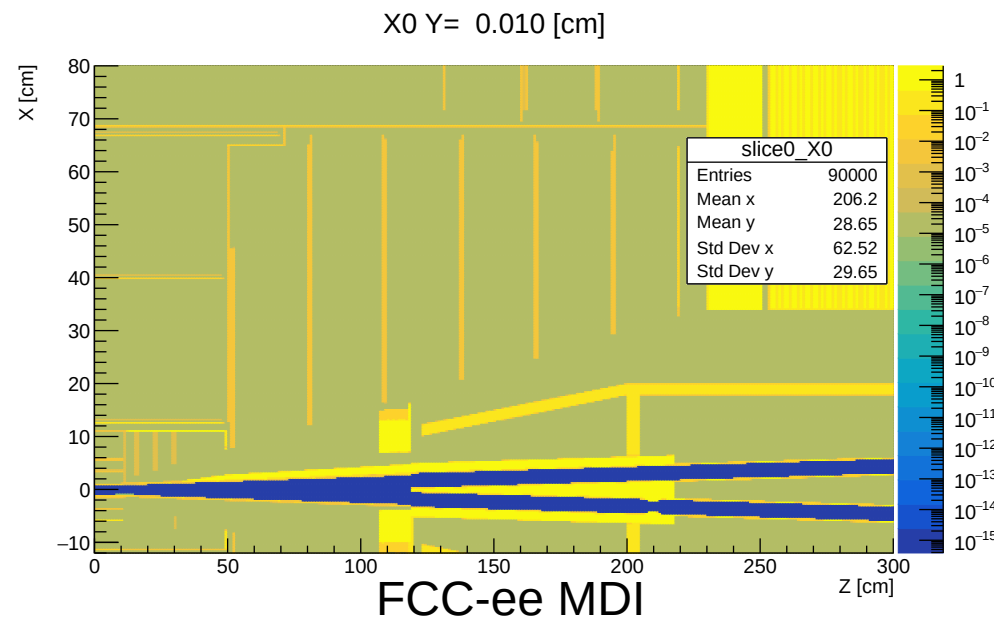
ILD (for ILC)

- ❖ ILC MDI
- ❖ Hybrid tracking layout



CLD (CLIC-like Detector)

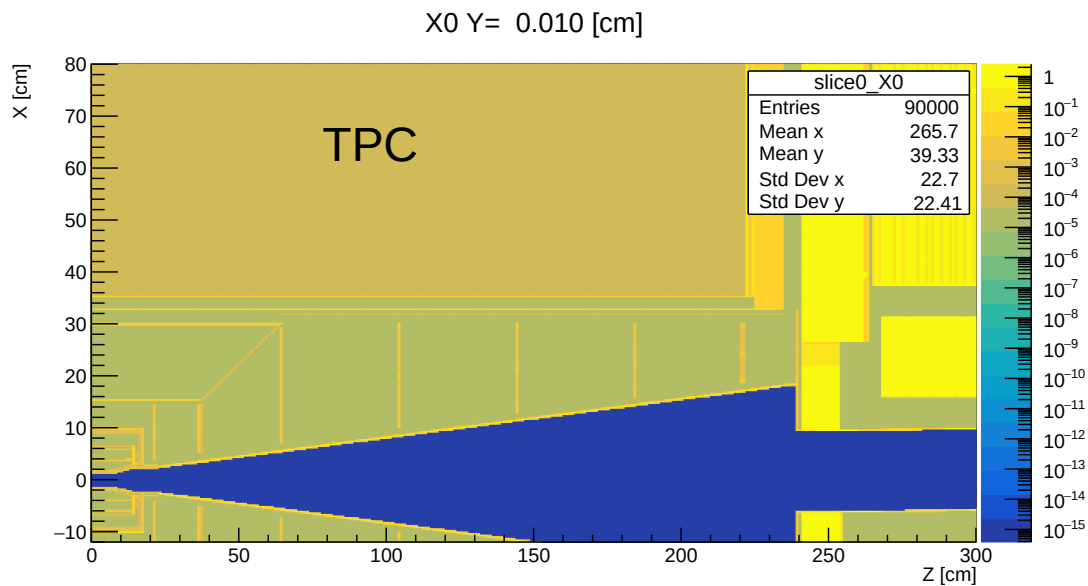
- ❖ FCC-ee MDI
- ❖ All-silicon tracking



Starting Point

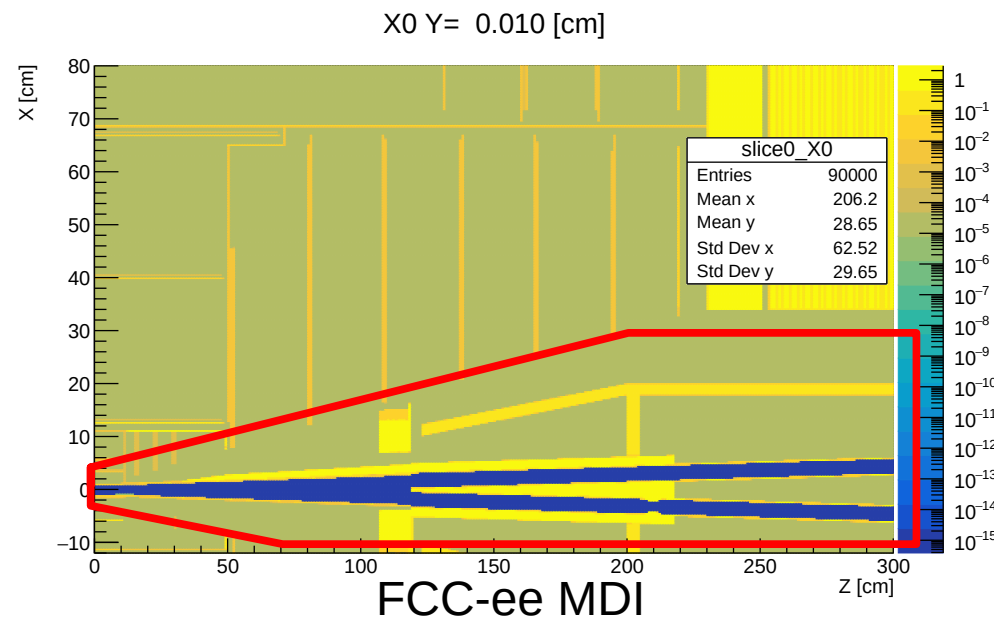
ILD (for ILC)

- ❖ ILC MDI
- ❖ Hybrid tracking layout



CLD (CLIC-like Detector)

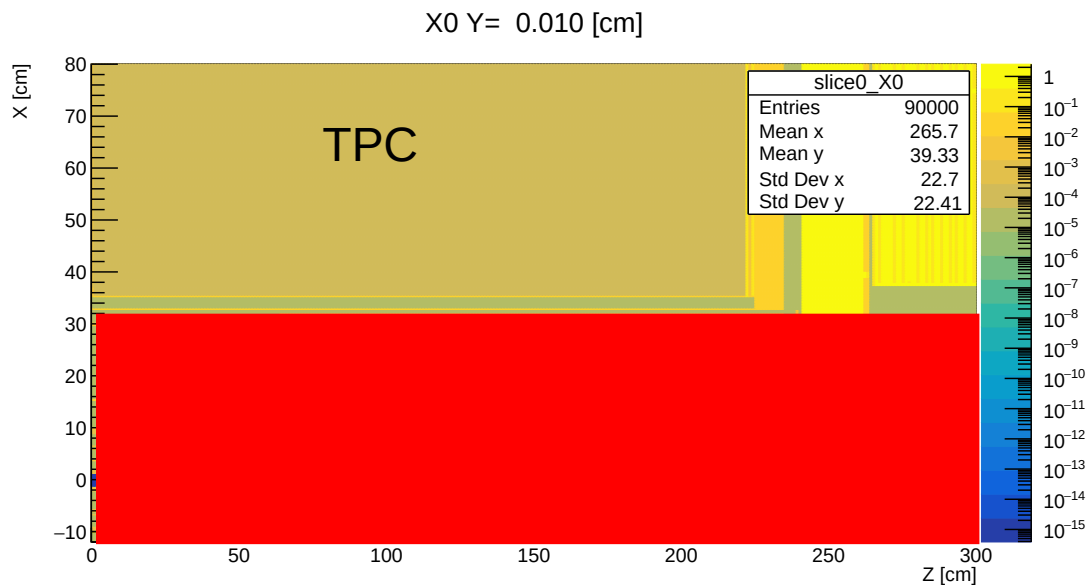
- ❖ FCC-ee MDI
- ❖ All-silicon tracking



Ansatz

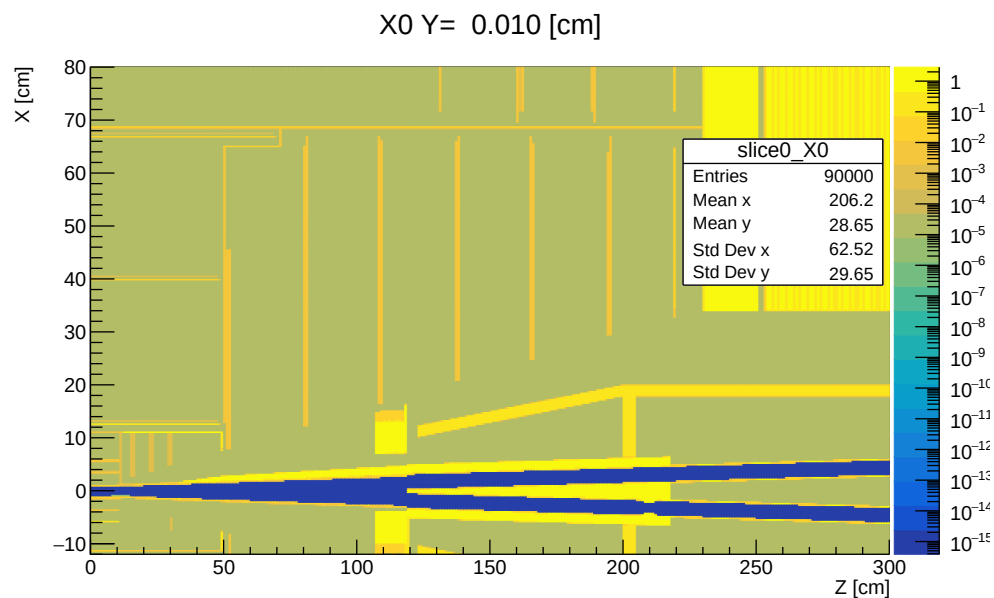
ILD (for ILC)

- ❖ ILC MDI
- ❖ Hybrid tracking layout



CLD (CLIC-like Detector)

- ❖ FCC-ee MDI
- ❖ All-silicon tracking

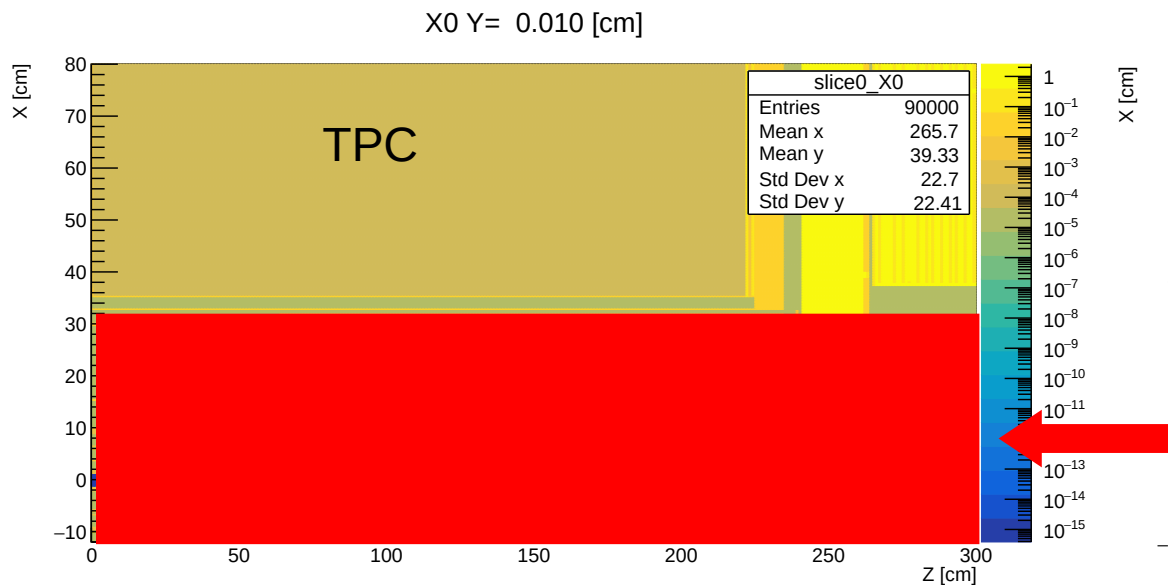


- Ansatz:**
- 1) Remove everything inside of the TPC from ILD
 - 2) Replace with CLD subdetectors

Ansatz

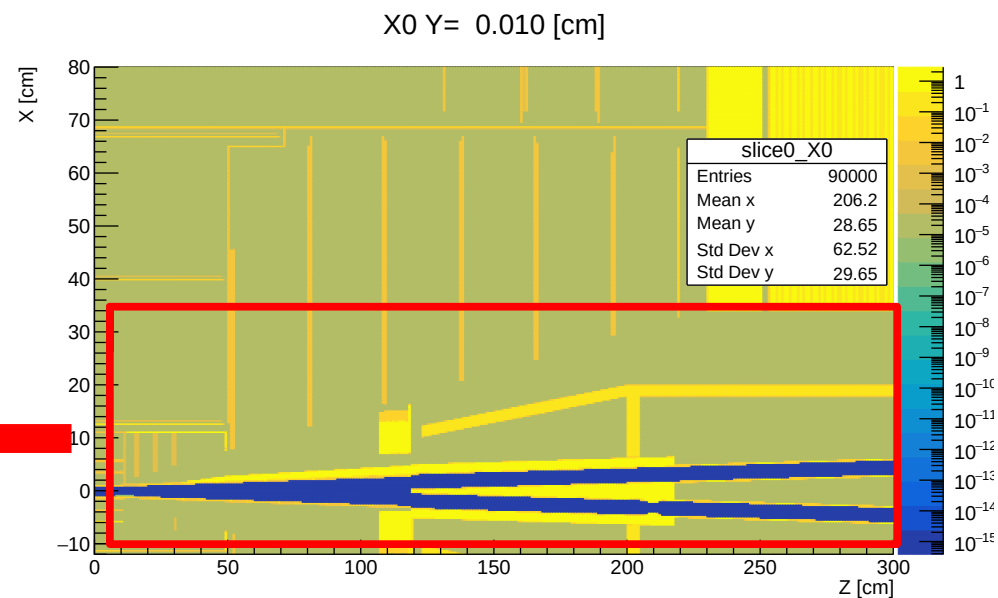
ILD (for ILC)

- ❖ ILC MDI
- ❖ Hybrid tracking layout



CLD (CLIC-like Detector)

- ❖ FCC-ee MDI
- ❖ All-silicon tracking

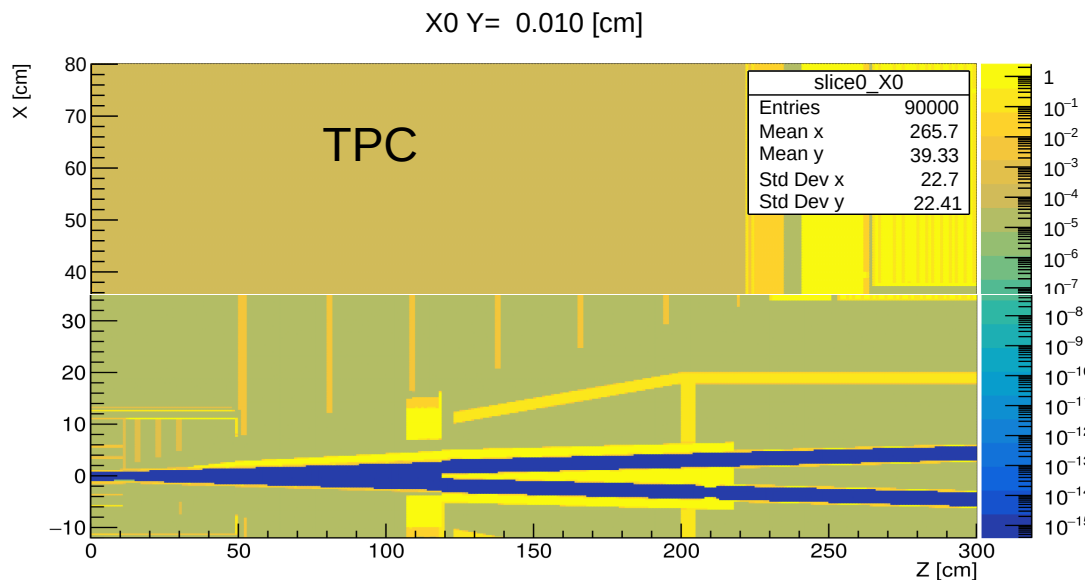


- Ansatz:**
- 1) Remove everything inside of the TPC from ILD
 - 2) Replace with CLD subdetectors

Ansatz

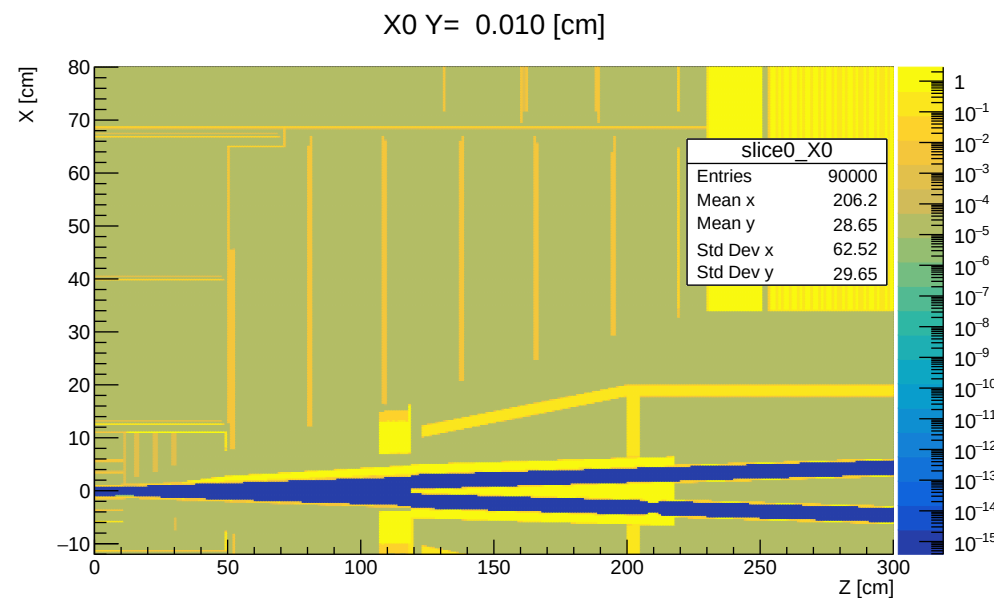
ILD (for ILC)

- ❖ ILC MDI
- ❖ Hybrid tracking layout



CLD (CLIC-like Detector)

- ❖ FCC-ee MDI
- ❖ All-silicon tracking

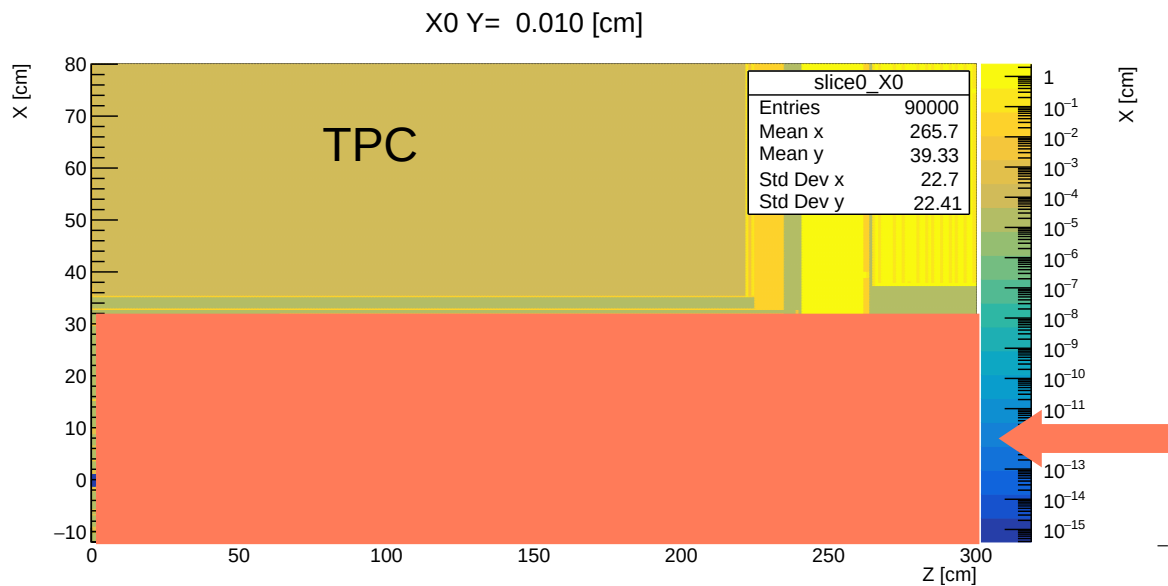


- Ansatz:**
- 1) Remove everything inside of the TPC from ILD
 - 2) Replace with CLD subdetectors

Ansatz

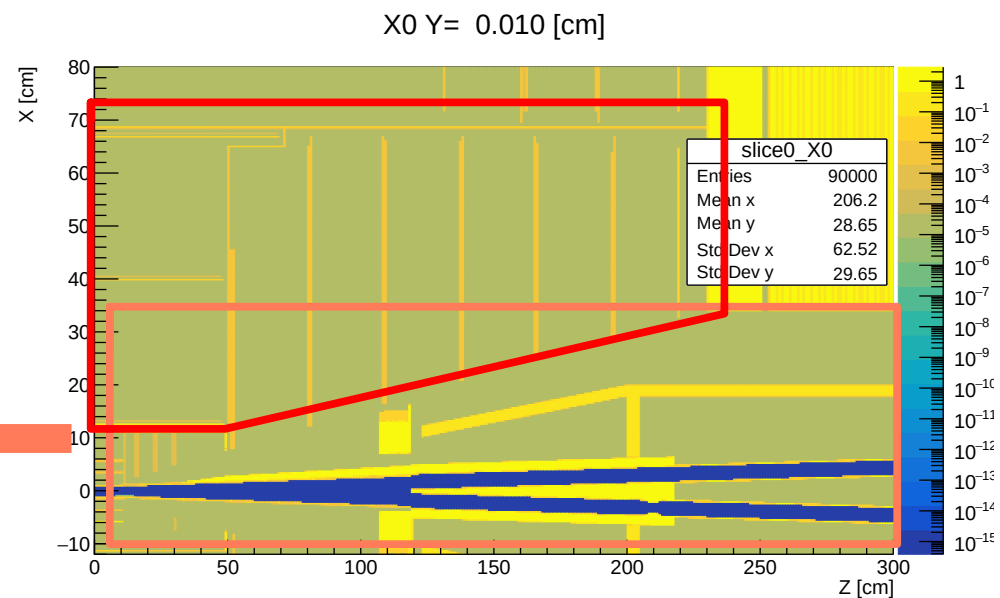
ILD (for ILC)

- ❖ ILC MDI
- ❖ Hybrid tracking layout



CLD (CLIC-like Detector)

- ❖ FCC-ee MDI
- ❖ All-silicon tracking



- Ansatz:**
- 1) Remove everything inside of the TPC from ILD
 - 2) Replace with CLD subdetectors

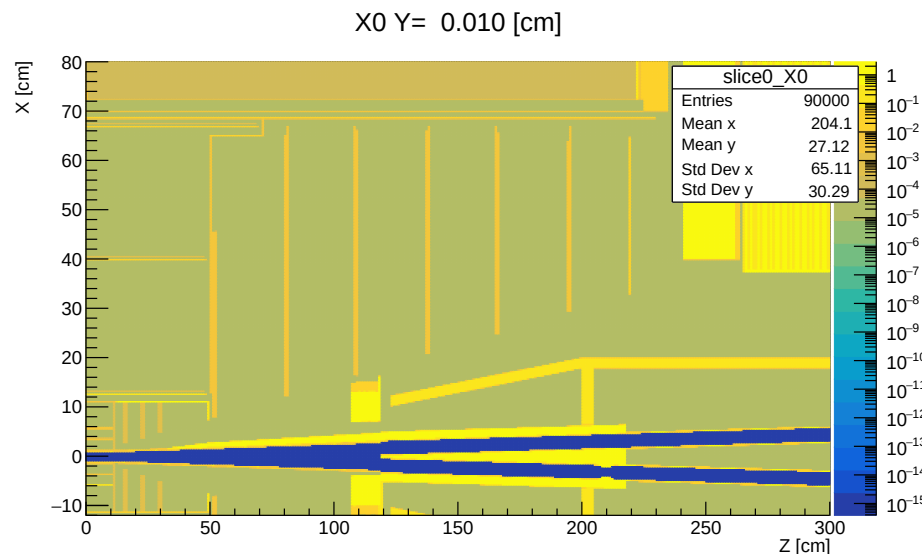
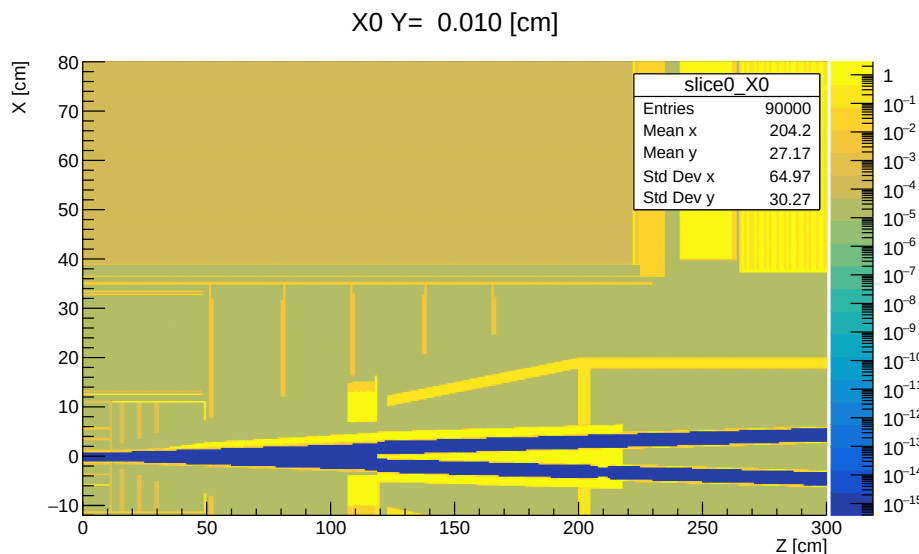
New Models or 2 Merging Strategies

ILD for FCC-ee **v01** – large TPC:

- ❖ Leave TPC as large as possible
- ❖ Squeeze Inner Tracker in between TPC and Vertex Detector

ILD for FCC-ee **v02** – small TPC:

- ❖ Copy Inner Tracker from CLD
- ❖ Shrink TPC to accommodate the IT



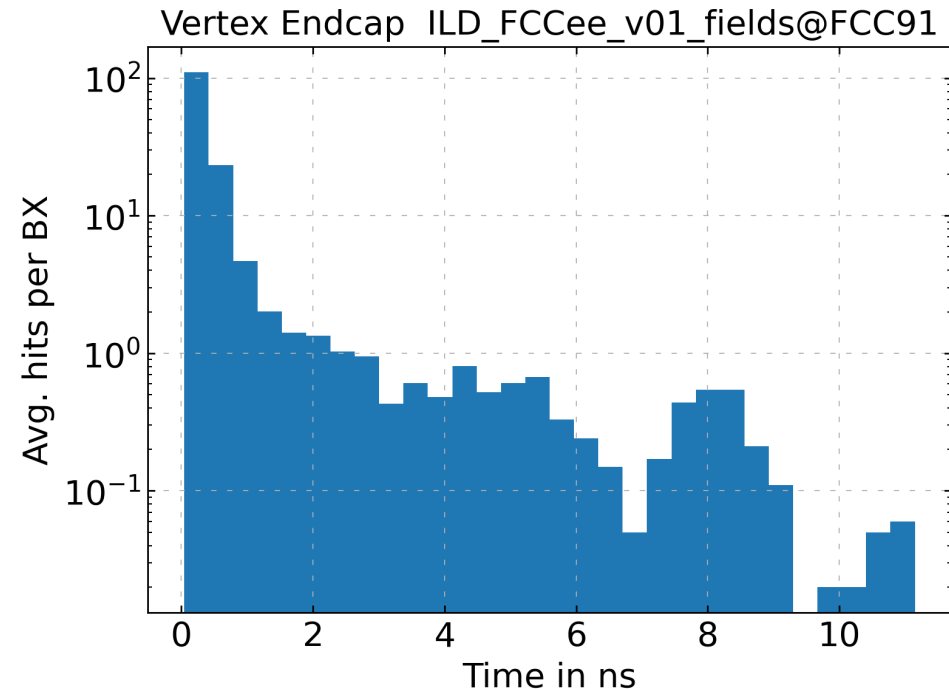
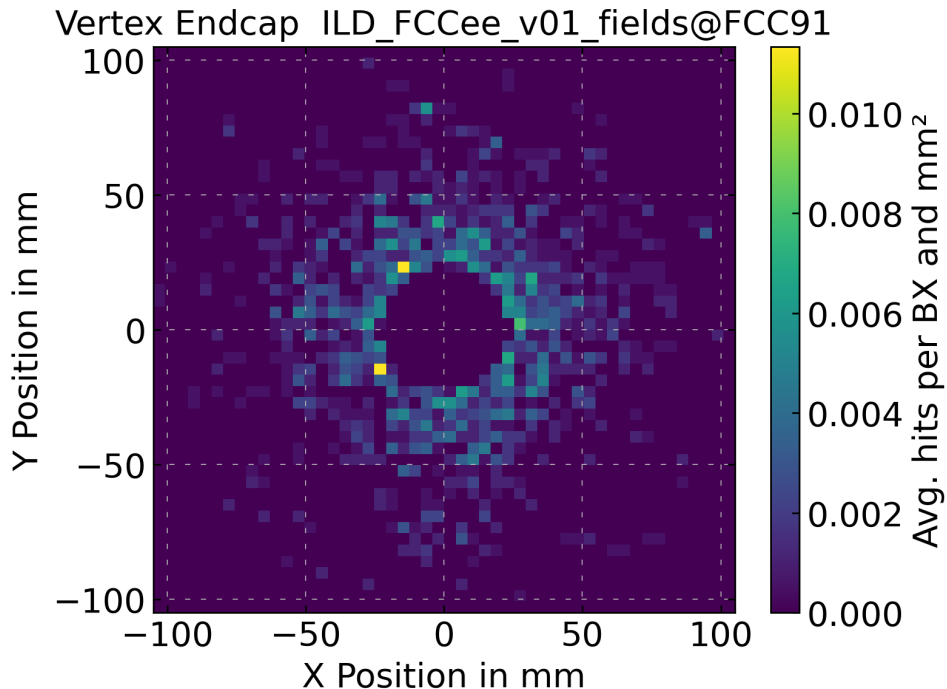
*Common MDI_o1_v00

*Calorimeter and solenoid volumes were left unchanged, except for removed ECal Ring and LHCal

model description source

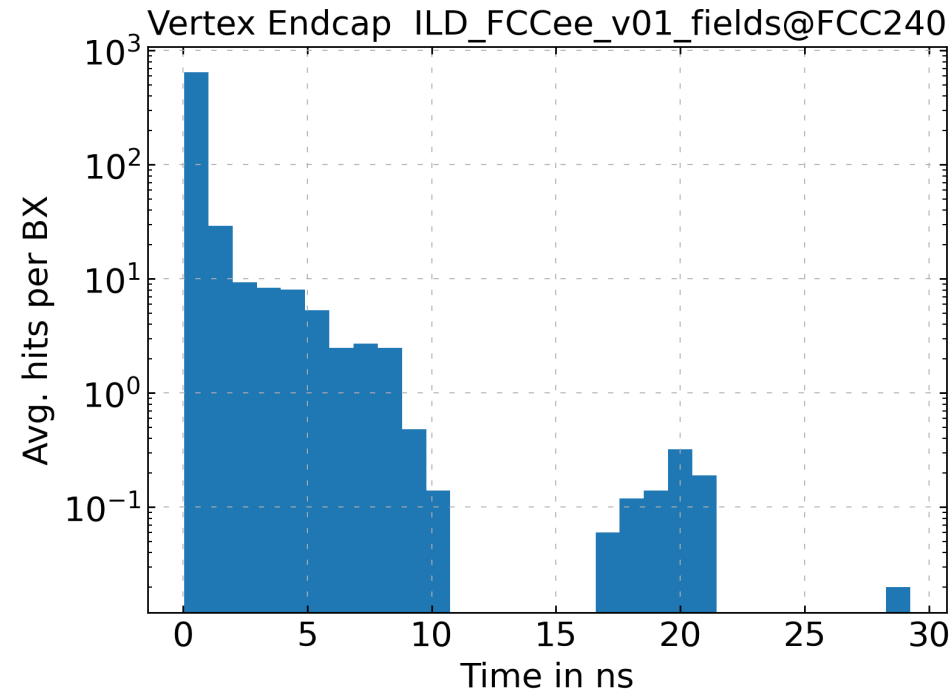
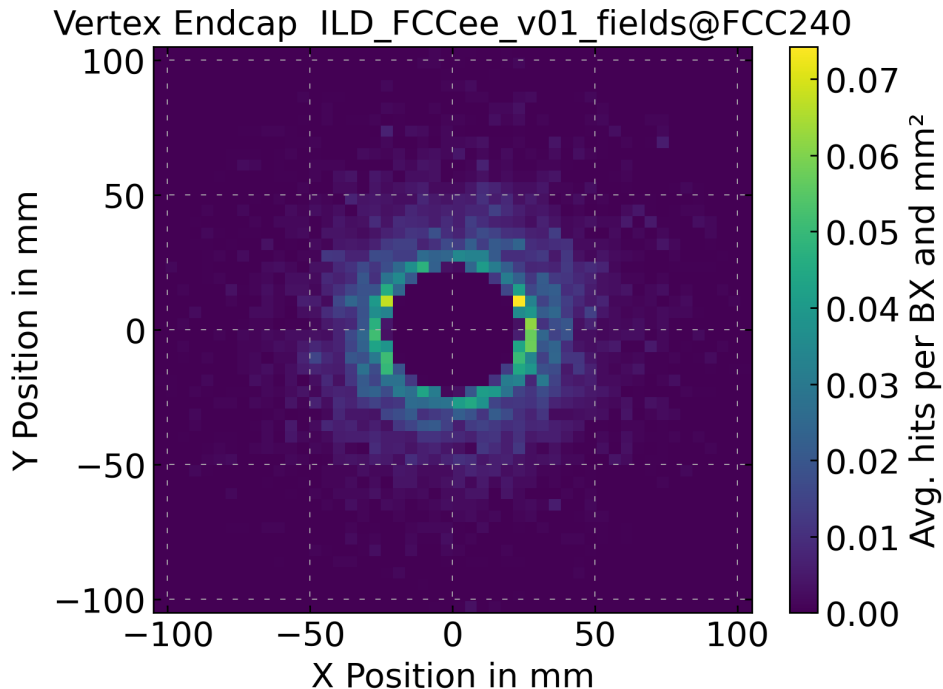
Hit Density in Inner Silicon Trackers

Vertex Endcap @ FCC91



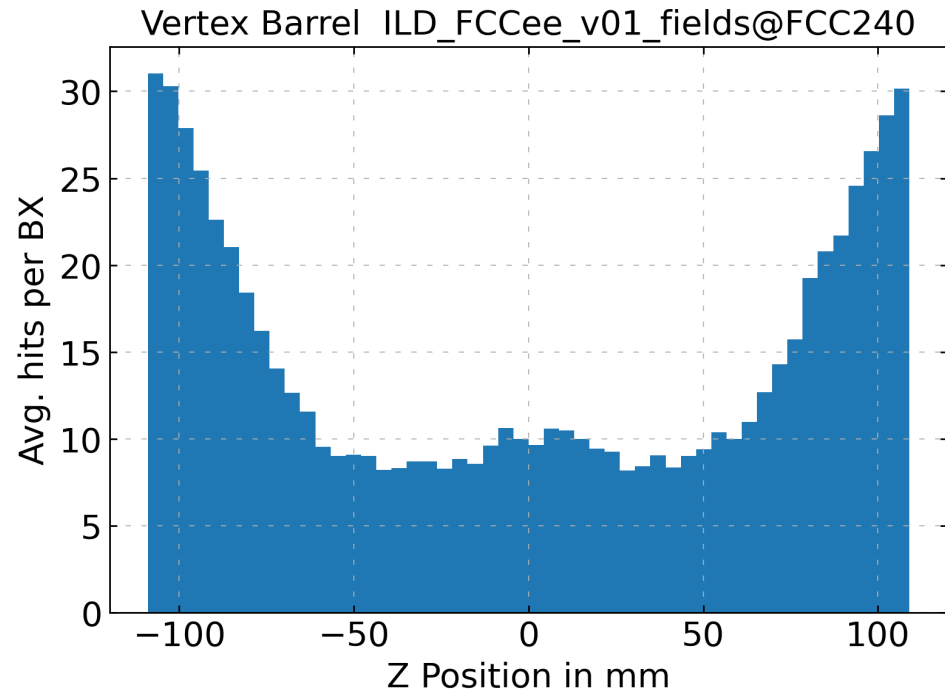
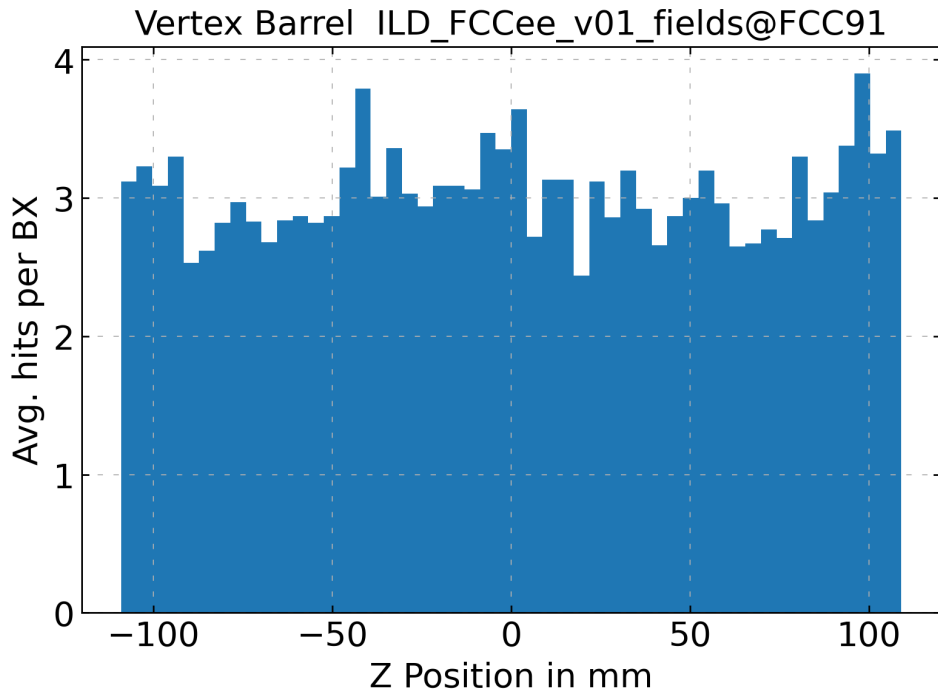
- ❖ Mostly prompt hits, some back-scattering
- ❖ Decreasing with radius

Vertex Endcap @ FCC240



- ❖ Mostly prompt hits
- ❖ Increased intensity
- ❖ Slightly more boosted

Vertex Barrel Occupancy @ FCC91 vs FCC240

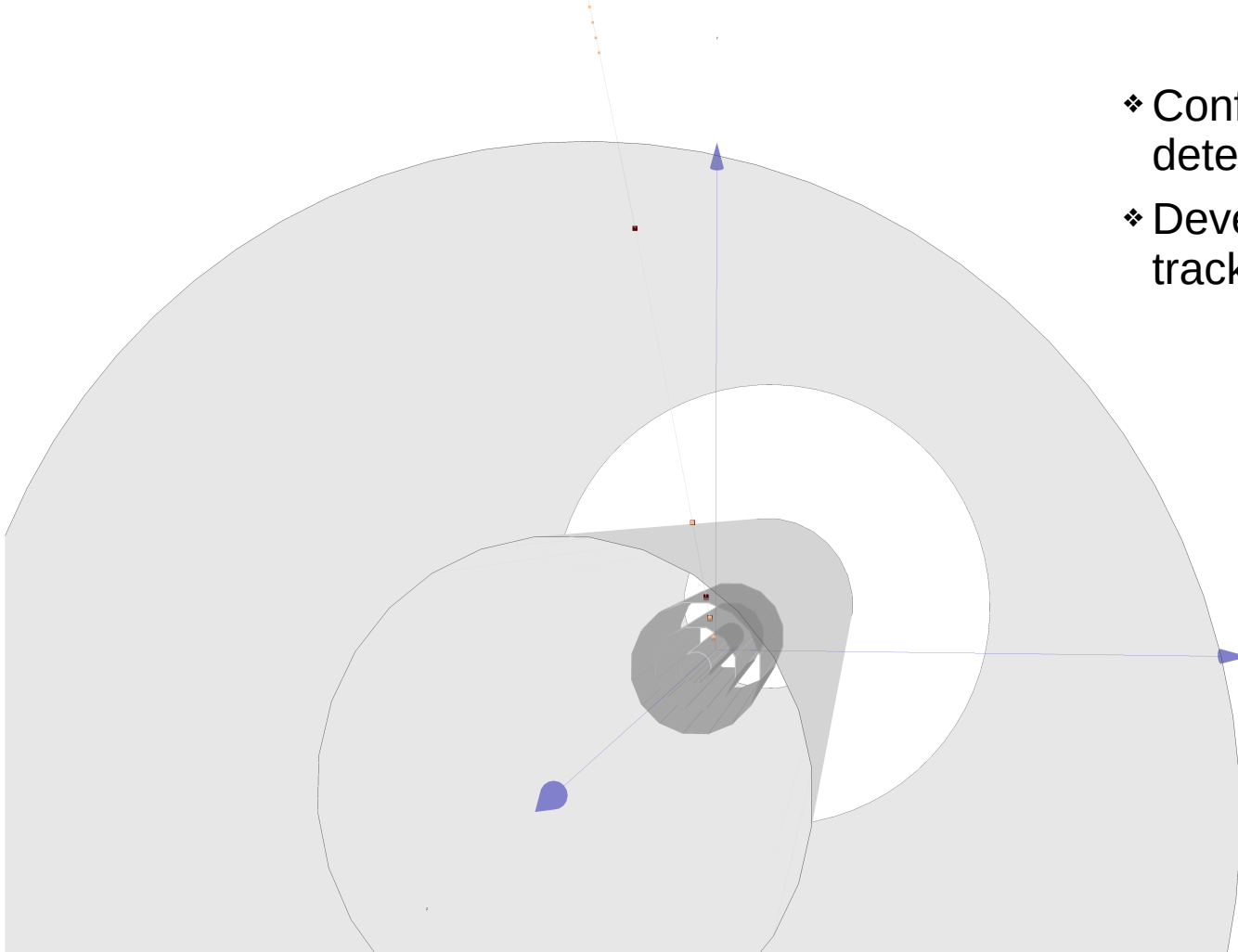


- ❖ Intensity increases with beam energy
- ❖ Beamstrahlung more boosted → hits shifted away from center
- ❖ Effect on tracking efficiencies to be studied

Tracking for Hybrid Layouts

Tracking w/ Hybrid Subdetector Technologies

- ❖ Conformal Tracking used for silicon detectors
- ❖ Developed for CLIC (full-silicon tracking)

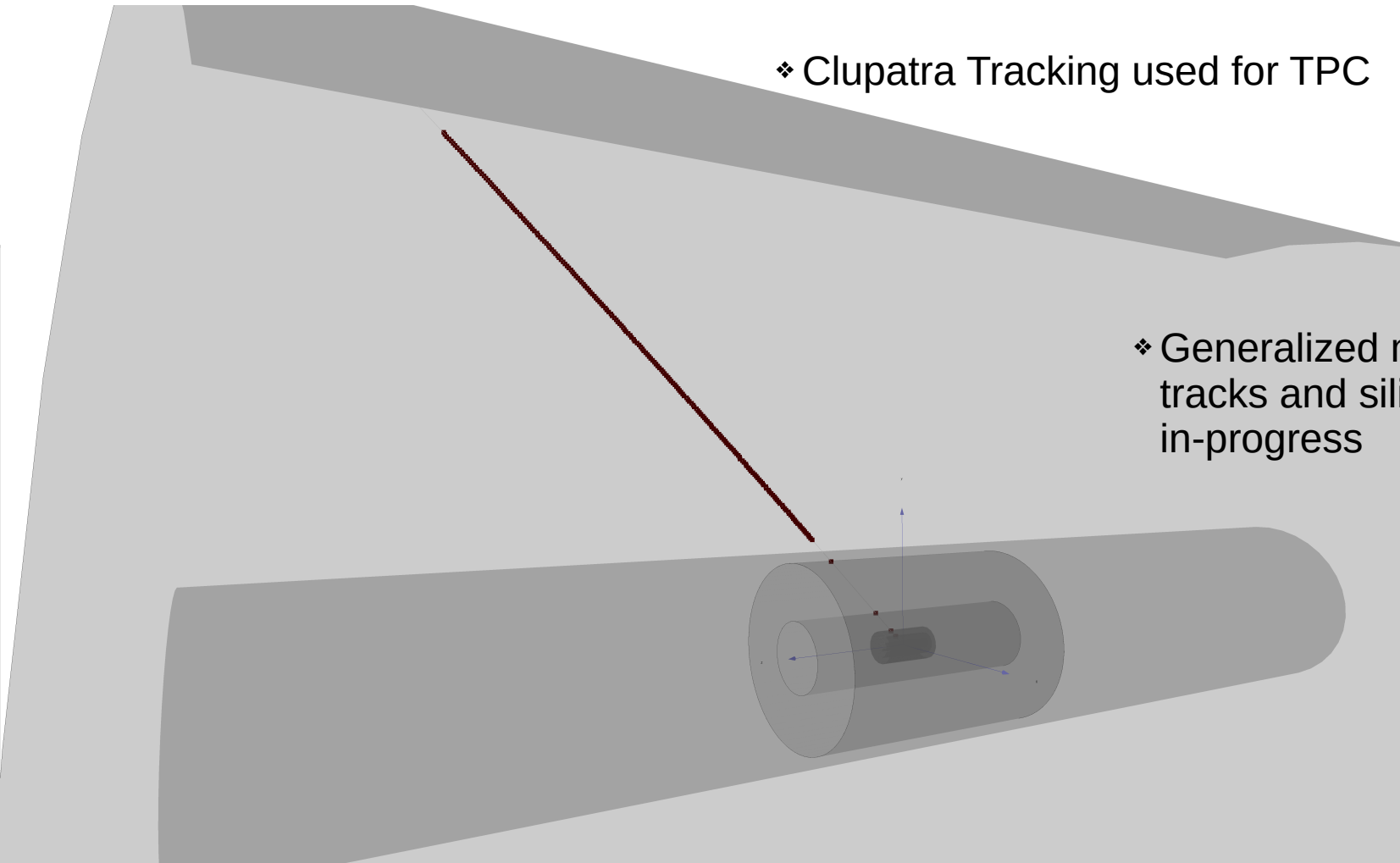


*ILD_FCCee_v01

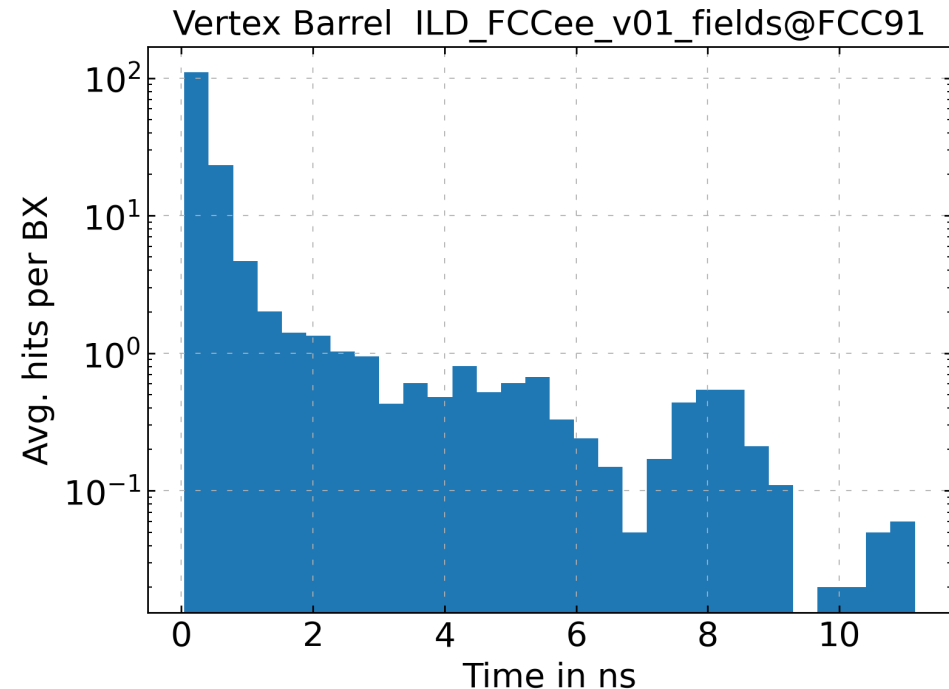
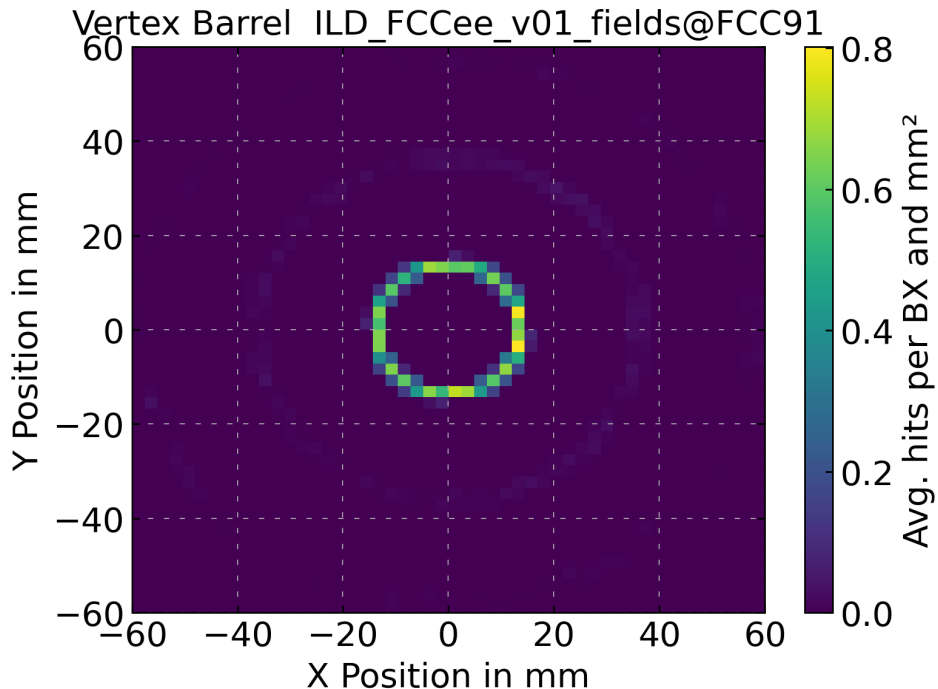
Tracking w/ Hybrid Subdetector Technologies

❖ Clupatra Tracking used for TPC

❖ Generalized merging of TPC tracks and silicon tracks is work-in-progress

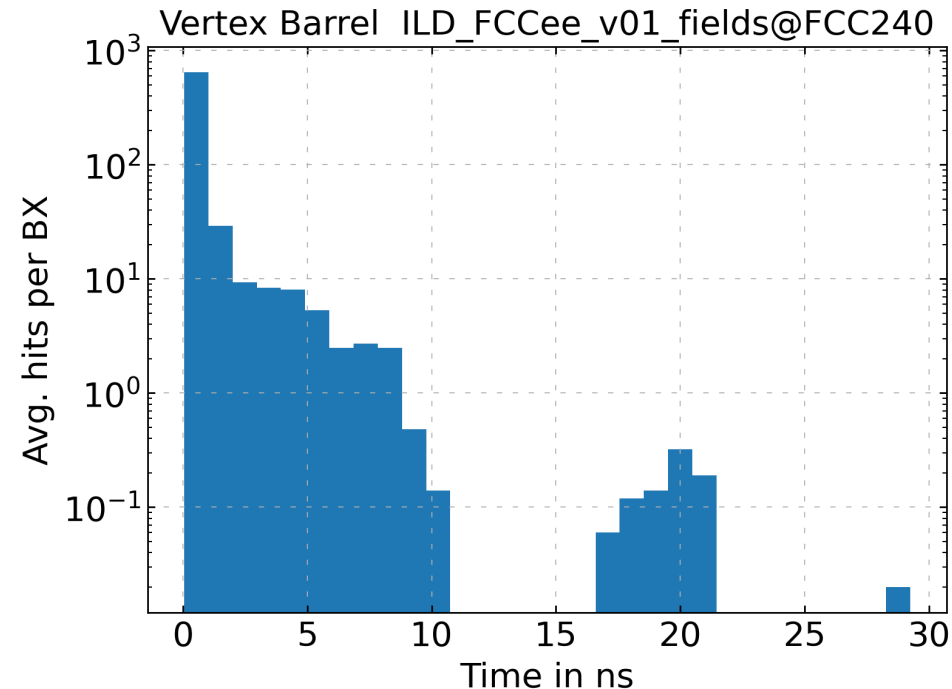
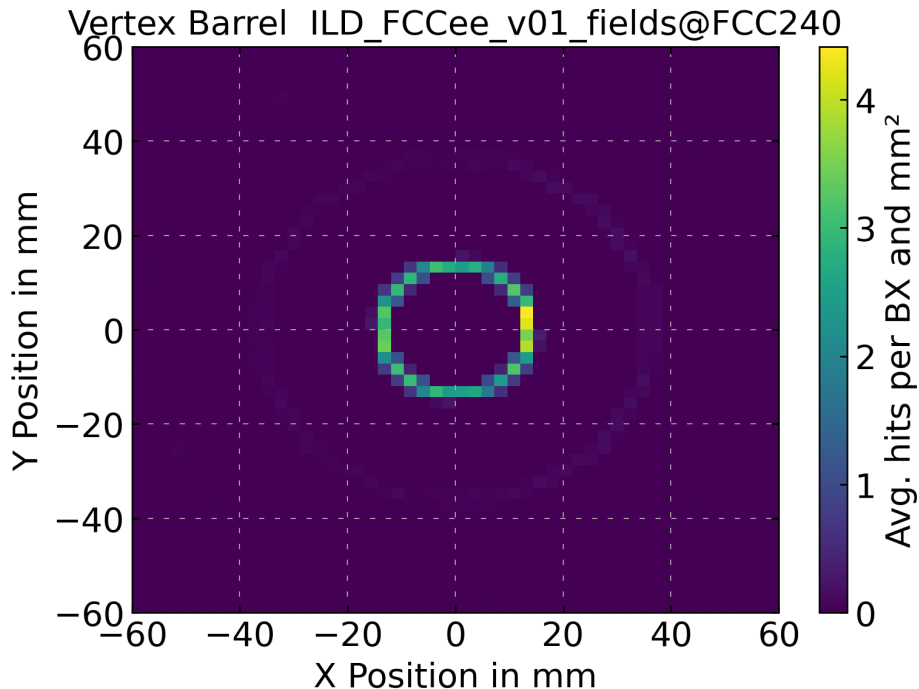


Vertex Barrel @ FCC91



- ❖ Mostly prompt hits, some back-scattering
- ❖ Intensity decreases with radius

Vertex Barrel @ FCC240

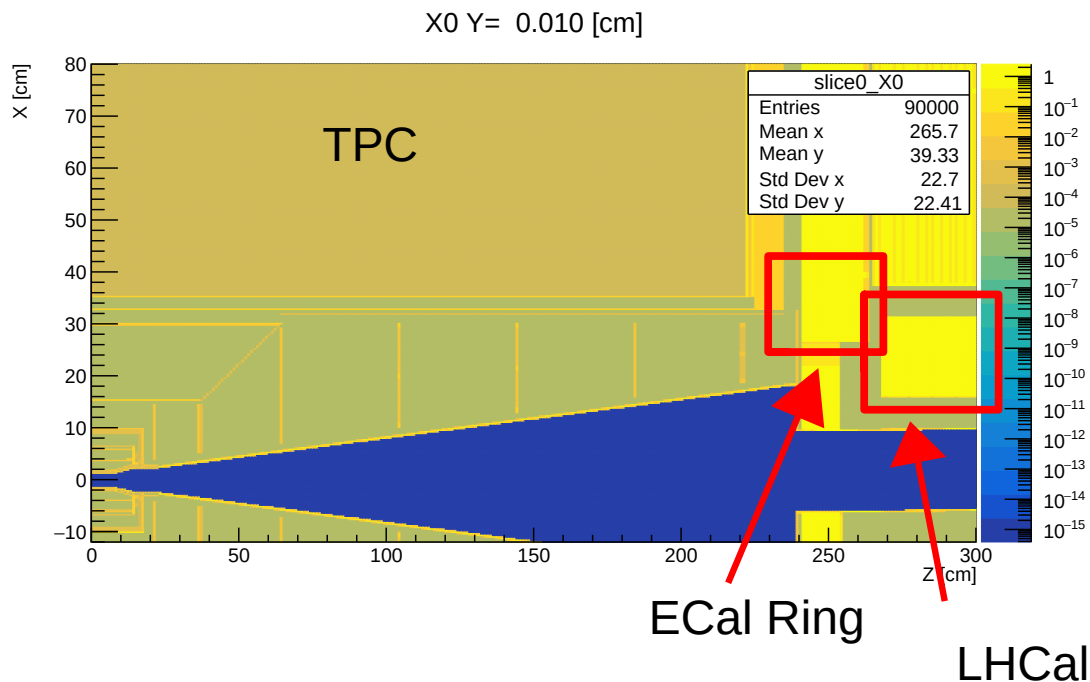


- ❖ Intensity increased
- ❖ Mostly prompt hits

Starting Point

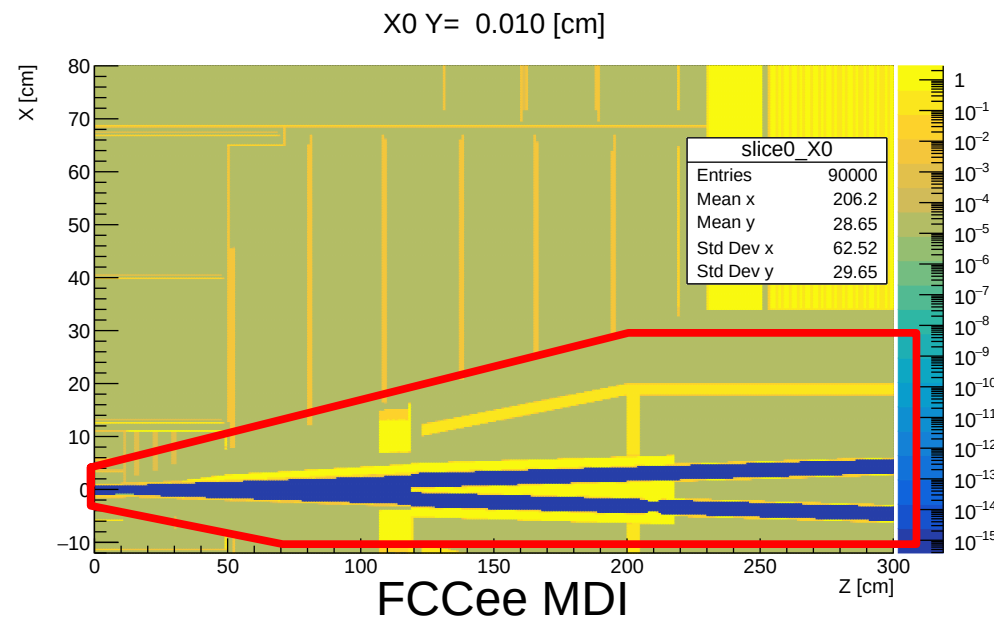
ILD (for ILC)

- ❖ ILC MDI
- ❖ Hybrid tracking layout



CLD (CLIC-like Detector)

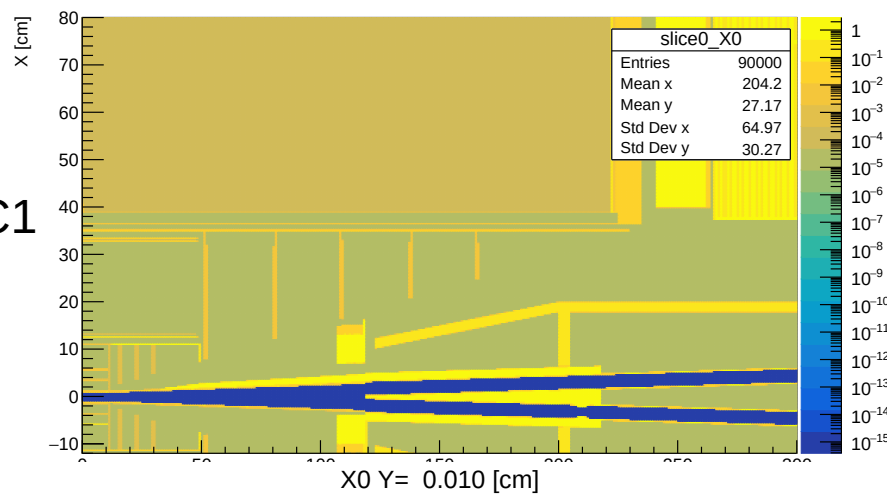
- ❖ FCCee MDI
- ❖ All-silicon tracking



Overview of FCC-ee Models

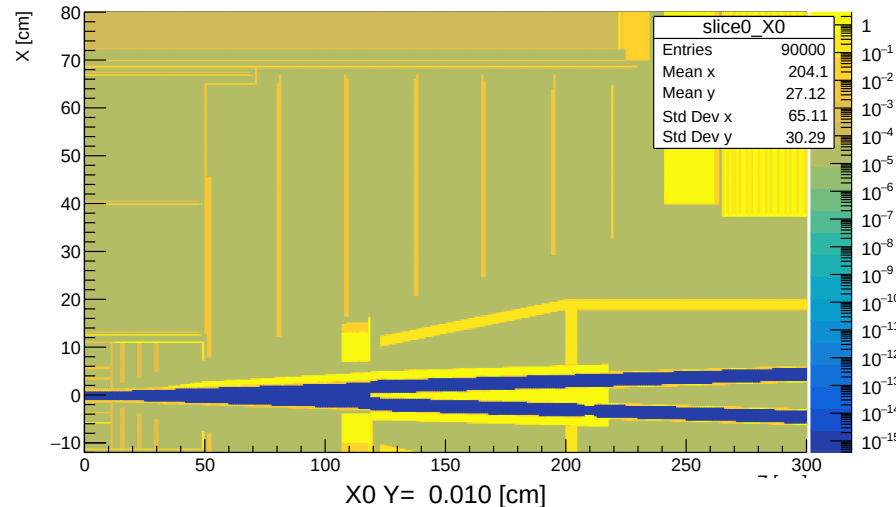
X0 Y= 0.010 [cm]

FCC1

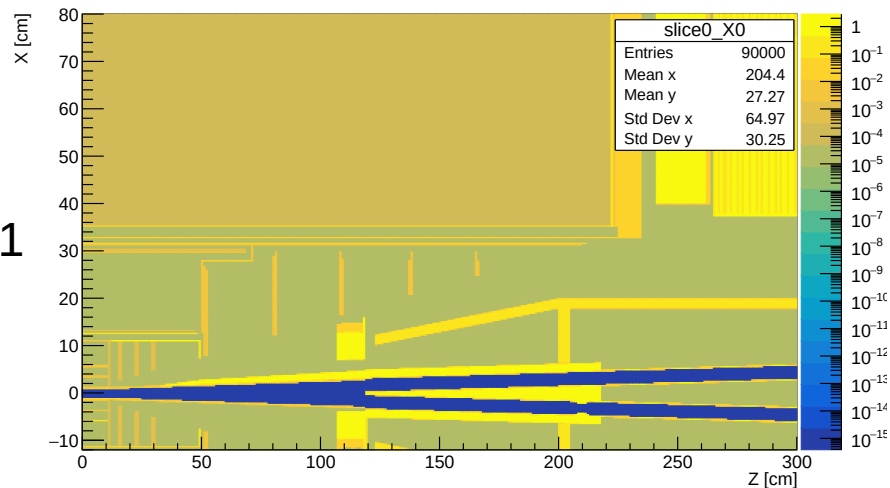


X0 Y= 0.010 [cm]

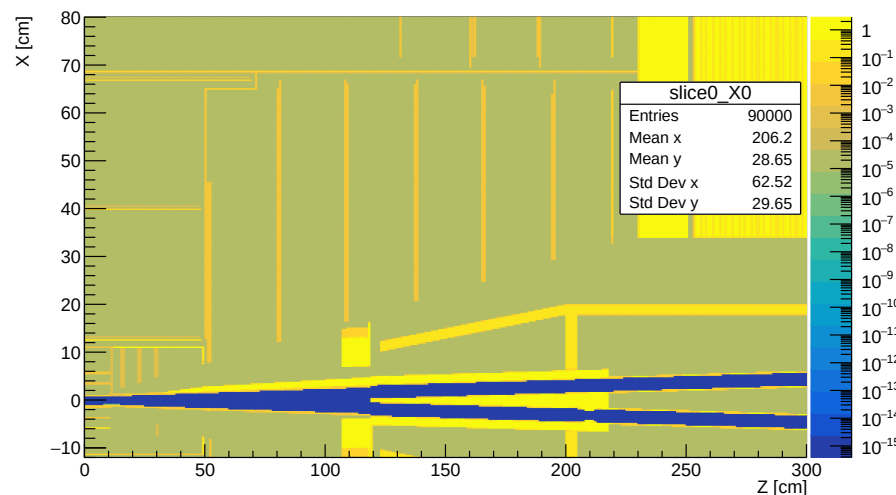
FCC2



v11



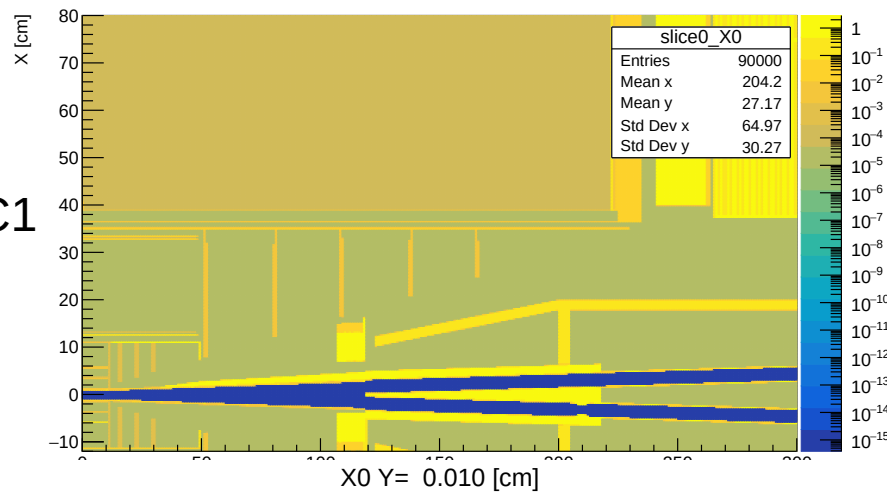
CLD



Overview of ILD Models

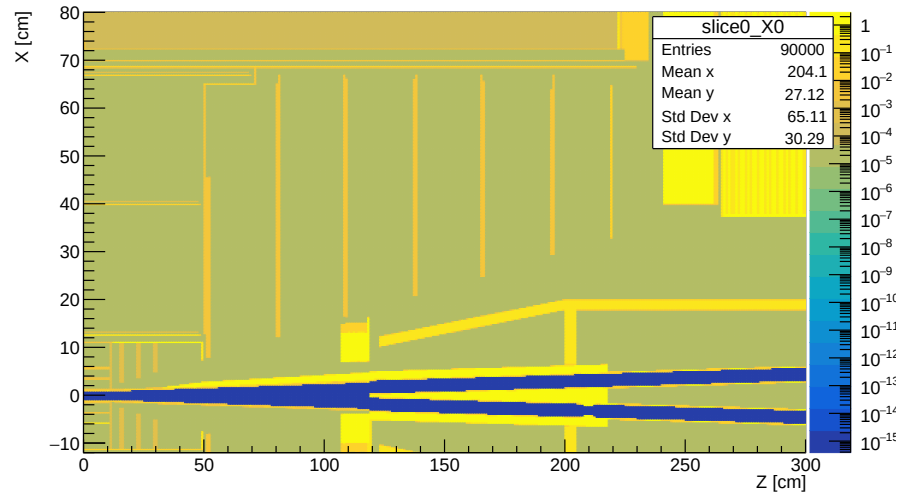
X0 Y= 0.010 [cm]

FCC1

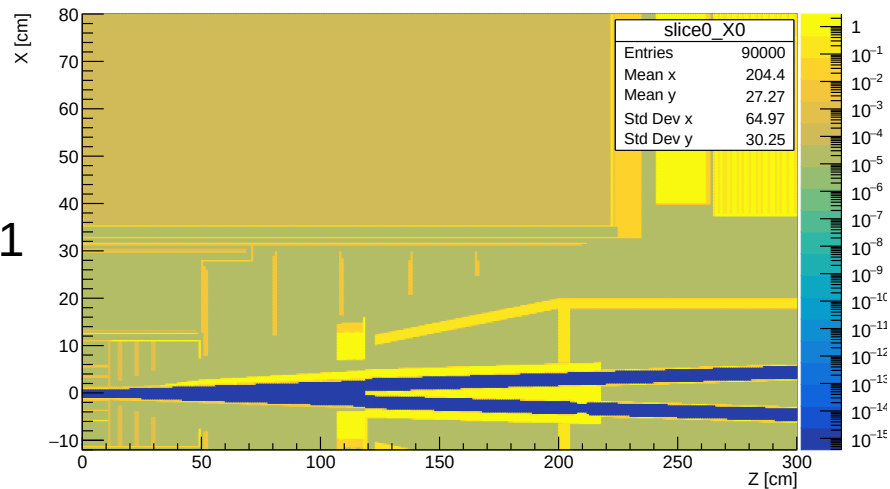


X0 Y= 0.010 [cm]

FCC2

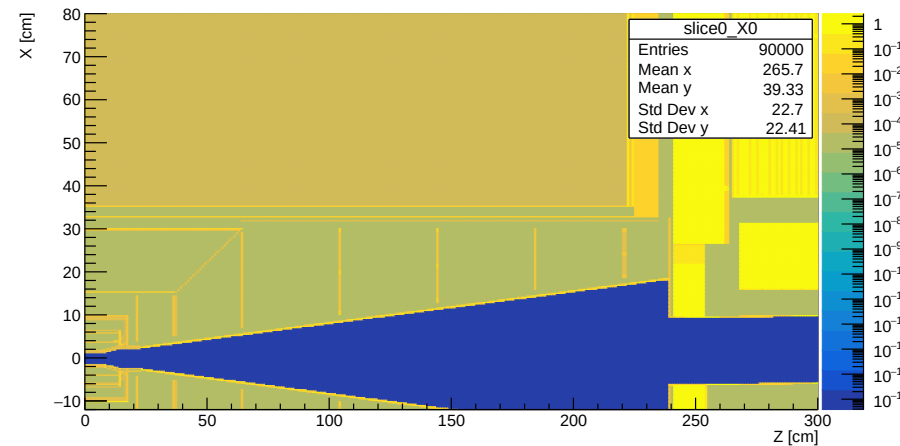


v11



X0 Y= 0.010 [cm]

v02



Tracking Subdetector Systems ILD vs CLD

ILD

- ❖ Hybrid tracking layout

ILD barrel trackers:

- ❖ VerTeX detector (VTX)
- ❖ Silicon Internal Tracker (SIT)
 - ❖ Two layers
- ❖ Time Projection Chamber (TPC)
- ❖ Silicon External Tracker (SET)
 - ❖ One layer

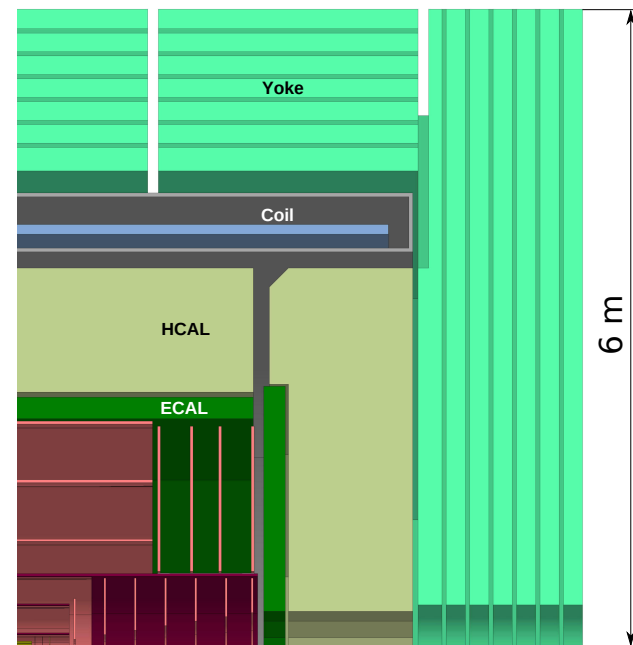
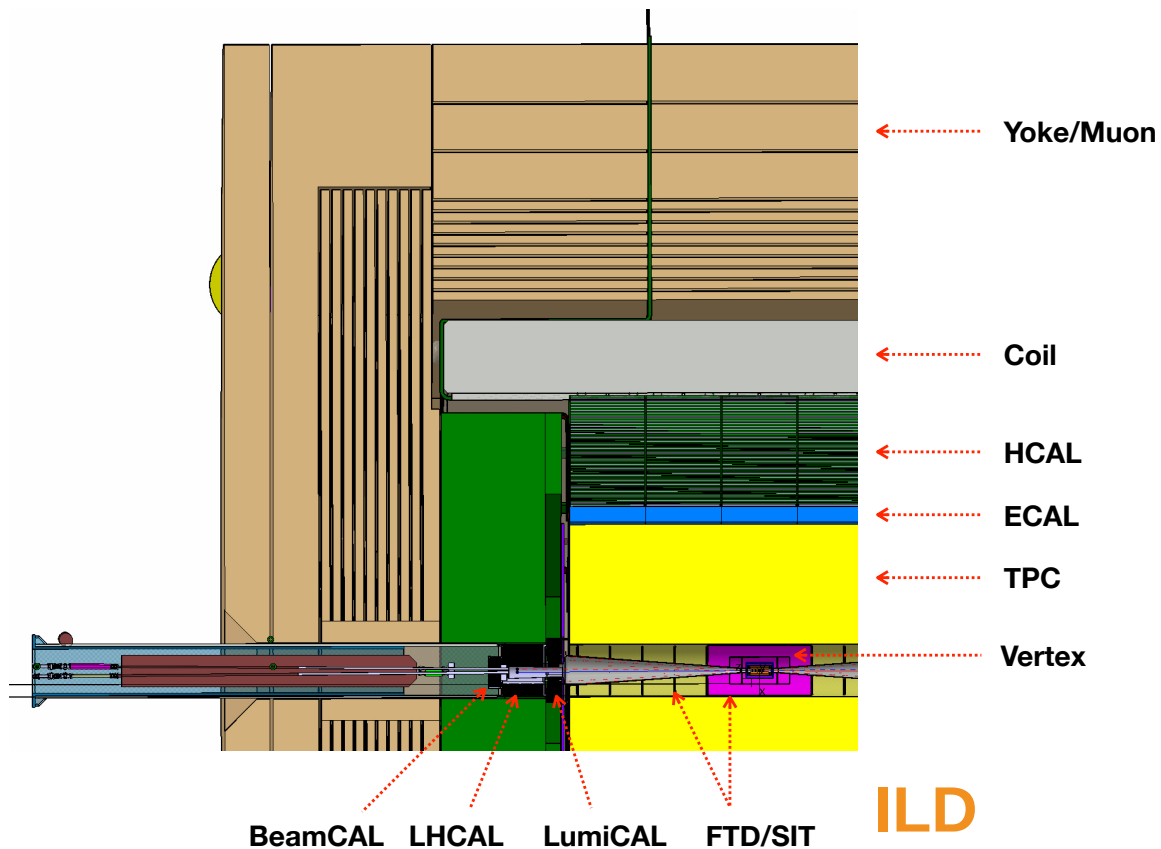
ILD disc/endcap tracker:

- ❖ Forward Tracking Detector (FTD)
 - ❖ 2 + 5 discs
- ❖ Endcap for VTX and SIT

CLD

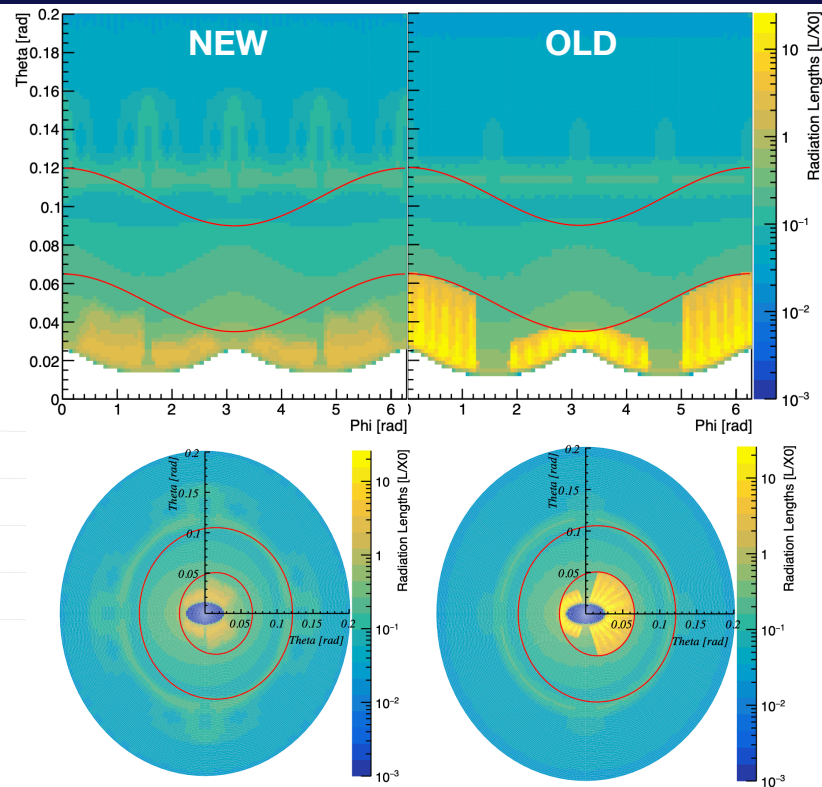
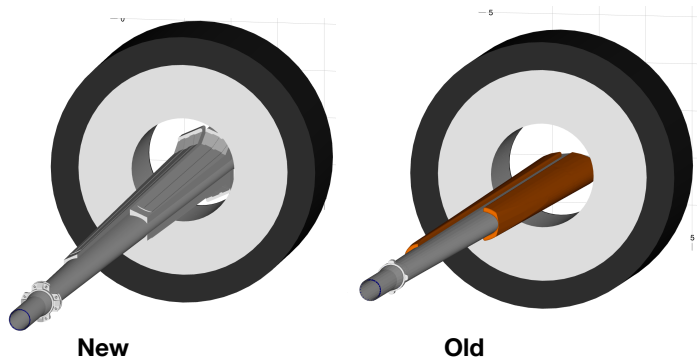
- ❖ All-silicon tracker
- ❖ All subdetectors: barrel + discs/endcaps
- ❖ **Vertex Detector:**
 - ❖ Three double layers + three double-discs on both sides
- ❖ **Inner Tracker:**
 - ❖ Three barrel layers + seven discs
- ❖ **Outer Tracker:**
 - ❖ Three barrel layers + four discs (enclosing the Inner Tracker discs)

ILD vs CLD



New beam pipe and cooling

After this feedback, a new solution for the trapezoidal chamber cooling was found. Cooling manifolds are now **all in AlBeMet162** and are placed at **safety margin from the LumiCal acceptance**.



k4DetPerformance

- ❖ Framework designed to study tracking performance within full simulation environments
 - ❖ Requires complete simulation and reconstruction setup
 - ❖ Matches reconstructed tracks to simulated particles
 - ❖ Various plotting options: superimpose plots and ratios for comparative analyses
- ❖ Initially developed for CLD at FCCee by Gaelle Sadowski
- ❖ Now integrated into Key4HEP
- ❖ Leonhard Reichenbach, Gaelle and me are looking into extending its applicability to other detectors

<https://github.com/key4hep/k4DetPerformance>