Beam-background impact in the IDEA drift chamber

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FCC-ee physics & experiments:

Machine detector interface (review)

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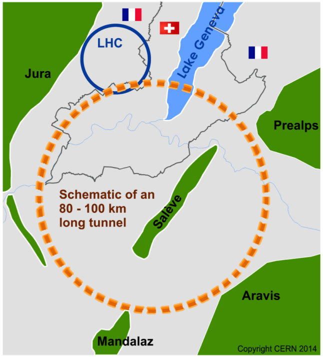
Introduction

FCCSW: FCC Software

- Common software for all FCC experiments
  - ee, hh & eh
- Detector and physics studies
  - Fast & full simulations
  - One software stack from event generation to physics analysis
- Collaborative approach



FCCee-IDEA & FCCSW

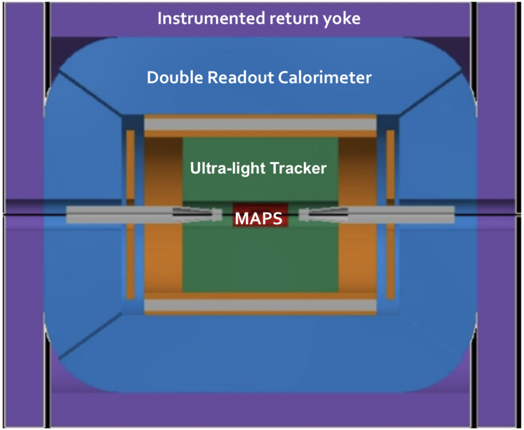
- A first example of implementation of the IDEA detector in FCCSW
- Validation of the detector
- Study of the impact of beam-background in the IDEA drift chamber

2 FCCee detector concepts

- The CLD detector concept (c.f. CLD detector model overview, Oleksandr Viazlo)
  - An adaptation of the CLIC detector model
    $\Rightarrow$ (Silicon-based vertex and tracking detectors)
  - Widely simulated with the ILCSoft
- The IDEA detector concept $\Rightarrow$ focus of this talk

IDEA: Ultimate Goal

- Vertex detector: MAPS
- Ultra-light drift chamber with PID (DCH)
- Double read-out calorimetry (DR)
- Additional disk layers to be placed in the space between DCH and DR
- 2 T solenoidal magnetic field
- Instrumented return yoke
- Surrounded by large tracking volume (R$\sim$8 m) for very weakly coupled (long-lived) particles



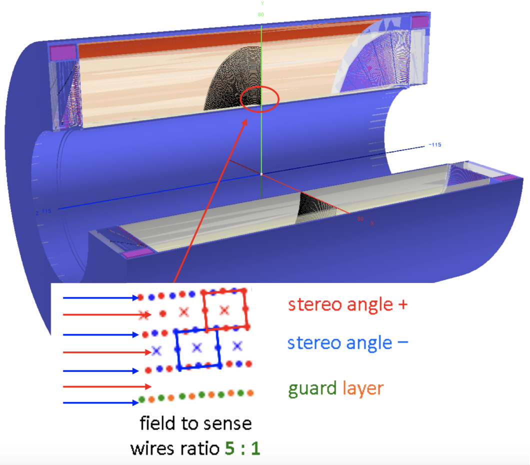
IDEA Drift Chamber (DCH)

- Track reconstruction & particle ID
- Layers divided into cells rotated with a certain stereo angle

Parameters

Length	4500 mm
Inner radius	345 mm
Outer radius	2000 mm
Nb. layers	112
Cell size	12 mm to 14.7 mm
Total nb. of sensitive wires	56448
Total nb. of field wires	282240
Total nb. of wires	338688
Gas	GasHe_90Isob_10
Wire material	Aluminum
Single cell resolution	0.1 mm

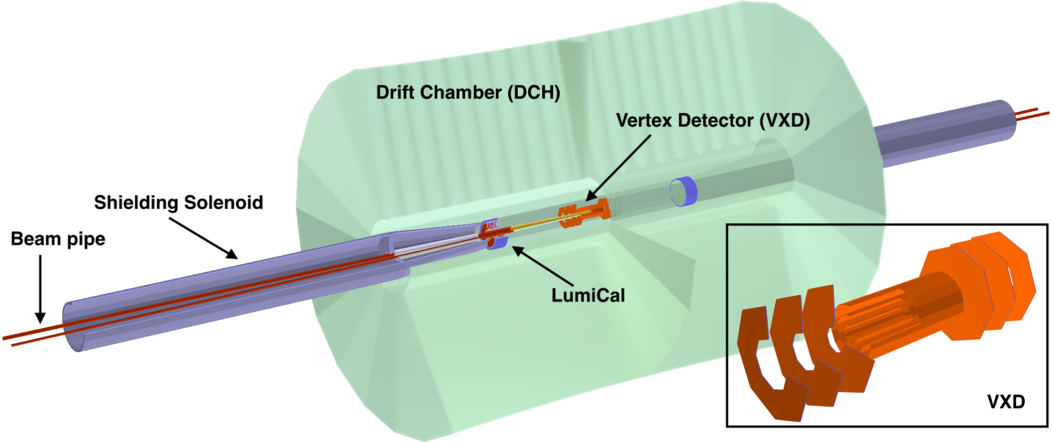
- Field wires: provide a uniform electric field
- Sensitive wires: record signal
- Field to sense wire ratio: 5:1



The interaction region as implemented in FCCSW

- Beam-pipe, beam instrumentations and the vertex detector are taken from the CLD concept
  - Temporary design of VXD for the IDEA detector ⇒ ultimate goal: MAPS
- The DCH implemented from scratch in FCCSW

Visualisation with FCCSW



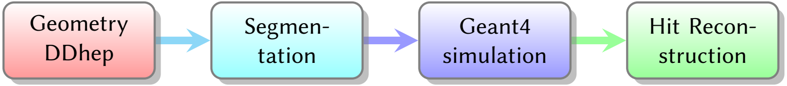
CLD vs. IDEA interaction region

- Both detectors have comparable coverage
- Difference in the tracking regions:
  - Number of layers
  - Material budget (and type)
  - CLD tracker separated in the endcap and the barrel regions

Parameters	FCCee (CLD)	FCCee (IDEA)
VXD Barrel r_{in}	17 mm	17 mm
VXD Barrel r_{out}	59 mm	59 mm
VXD Barrel length	250 mm	250 mm
VXD Endcap r_{in}	24 - 45 mm	24 - 45 mm
VXD Endcap r_{out}	102 mm	102 mm
VXD Endcap $z_{position}$	159-301 mm	159-301 mm
Tracker r_{in}	127 mm	345 mm
Tracker r_{out}	2100 mm	2000 mm
Tracker length	4720 mm	4500 mm

FCCSW simulation chain

1. Detector geometry description with DD4hep
   - Collaborative effort with CLIC, ILC and LHCb
   - The IR region and the VXD from CLD are as well implemented in DD4hep
   - Definition of the gas layers in the DCH
2. Segmentation of the sensitive areas:
   - Information on the position of the sense wires instead of placing physical volumes
   - Speed up the simulation
3. Geant4 simulation:
   - Calculate the E_{dep} for each ionisation action
   - Charge drift to the wires
4. Hit reconstruction:
   - Combination of individual hit calculations from (3)
   - Calculation of the signal in the wire

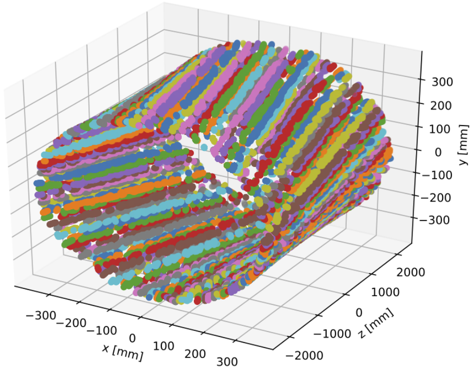


Segmentation of the DCH

- Information on the location of the sensitive wires
- Associates a unique wire ID (cellID) to the wires
- Different granularity for different layers in the DCH
- The segmentation information is created while building geometry

  $\Rightarrow$ Accessible in every step of the simulation

- First layer of the DCH
- Hits having the same wire ID are shown by the same color
- Validates the segmentation



Hit simulation and reconstruction of the DCH

Hit Simulation

- Geant4: Stepping in the gas with a G4Step length of 2 mm
- Reject ionisation acts with:
  - $E_{dep} < 10$ eV
  - `G4Step` length $< 5\mu$m
- Drift the charge deposition to the nearest wire
  - Compute the distance of the closest approach
  - Calculate the drift time assuming a constant drift velocity of 2 cm/μs
  - Calculate the total time of the hit

$$t_{hit} = t_{drift} + t_{\text{signal}} + t_{\text{particle flight}} \tag{1}$$

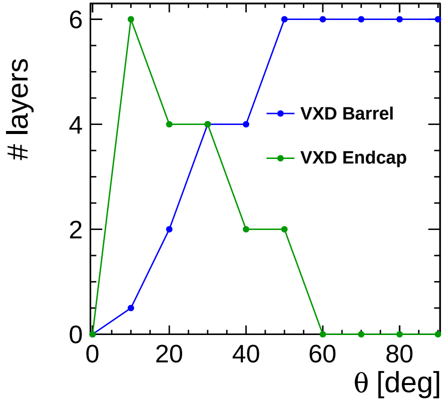
Reconstruction

- Hit: regroup the E_{dep} with a drift time smaller than the maximum drift time in the cell

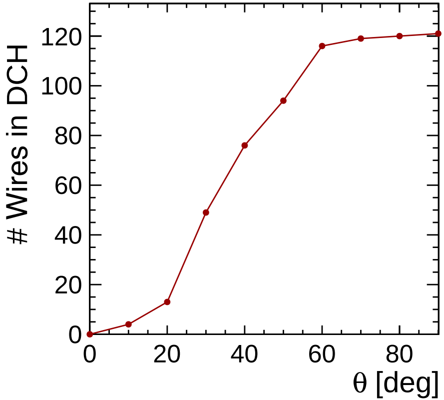
Number of sensitive layers vs. θ

- Number of layers hit by 100 GeV $\mu-$
  - $\theta = 0^\circ$: in the forward direction
  - $\theta = 90^\circ$: in the barrel
  - Averaged over ϕ

VXD

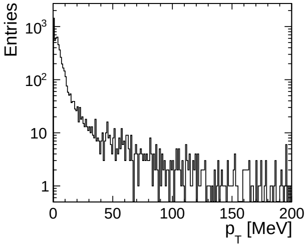


DCH

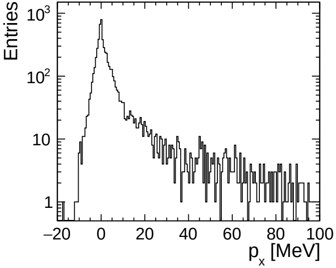


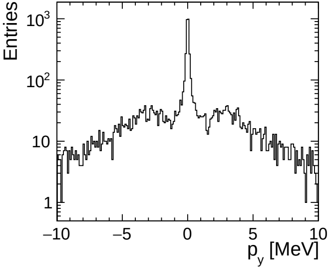
Impact of the beam background on the interaction region (IR)

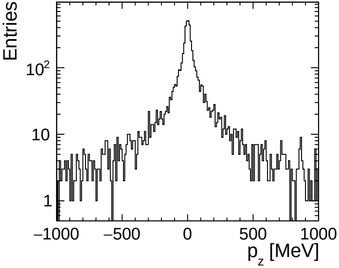
- The effect of e^+e^- pairs from $\gamma\gamma$ collisions (dominated by beamstrahlung photons)
- Pairs generated using GuineaPig (c.f. Georgios Voutsinas)
- E_{cm} = 365 GeV
- Total nb. of particles: $\sim$ 6200



Momentum distribution

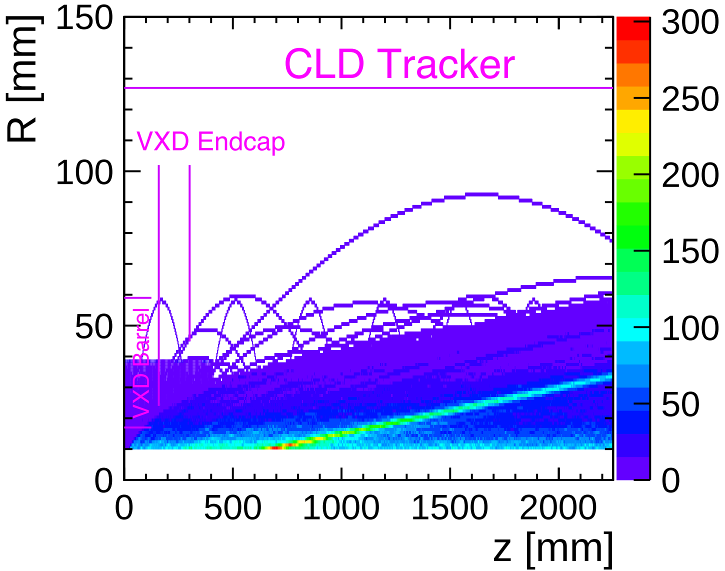






Pair particles in the detector

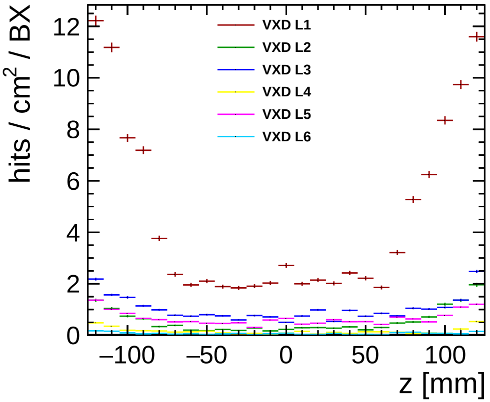
- Pair particles production in 1 BX
- The detector parts are highlighted
- A fortiori, no tracks reach the DCH wires



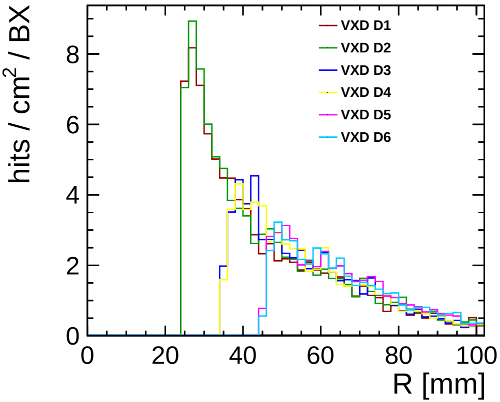
Impact of incoherent pairs in the VXD

- The number of hits is averaged over 30 BX

- Vertex Barrel



- Vertex Endcap

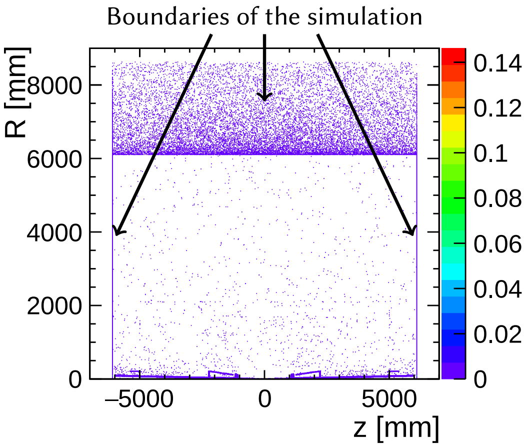


- Comparisons with the ILCSoft in progress & encouraging
- The level of this background does not pose problem for pattern recognition

Impact of incoherent pairs in the DCH: work in progress

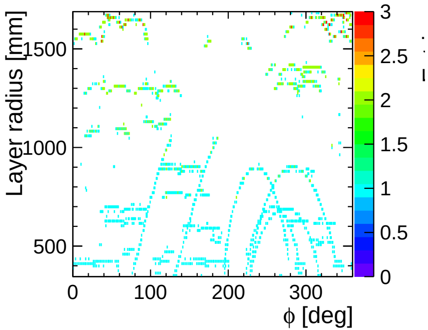
- On average ~ 2000 wires (over 56448) per BX are hit in the DCH (~ 3.5% of occupancy)
- Expected acceptable level of occupancy for a successful pattern recognition: ~ 5%
- Most of the hits are due to the backscattering
- The estimation of the occupancy is pessimistic due to unclear behaviour of GEANT4 at the boundary conditions and the lack of calorimeter, magnet and yoke around the DCH in the simulation
  ⇒ **Work in progress - stay tuned!**

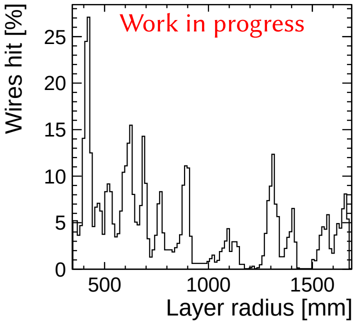
- Vertices of backscattering particles



Impact of incoherent pairs in the DCH: occupancy for one BX

- Pattern recognition possible for occupancy levels of:
  - 20% for inner-most layers
  - 5% for outer-most layers





- The readout time of the wires (dead time): 400 ns
- At the Z stage (E_{cm}=91.2 GeV, bunch spacing: 20 ns), an occupancy of 2000 wires per BX becomes critical
  $\Rightarrow$ Possible compensation by having 10$\times$ less background (than E_{cm}=365 GeV where the studies have been made)? → **To be studied!**

Summary & Outlook

- Full simulation of the FCCee-IDEA detector concept with FCCSW
- Implementation of the drift chamber $\Rightarrow$ geometry, segmentation, simulation & reconstuction
- Validations done and still ongoing
- First physics studies:
  - Impact of beam-induced backgrounds: e^+e^- pairs from $\gamma\gamma$ collisions
  - Estimation of the occupancy in the VXD and DCH with FCCSW and comparison with ILCSoft
  - Small occupancy due to the incoherent pairs in the VXD
  - More investigation on the occupancy is needed for the DCH to draw final conclusions
- Future work:
  - Implementation of a realistic material around DCH for a realistic estimate of the background
  - Study the effect of the synchrotron radiation & $\gamma\gamma \rightarrow$ hadrons
  - Optimisation of the geometry of the DCH
  - Track reconstruction in FCCSW

Backup slides

Segmentation Strategy for DCH

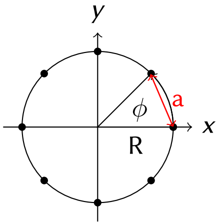
- Large number of wires $\Rightarrow$ requires a fast way to find the location of the closest wire hit
- Compute the azimuth angle of the hit ϕ for (x_{hit}, y_{hit})
  - (like if the wires were parallel to the z-axis).

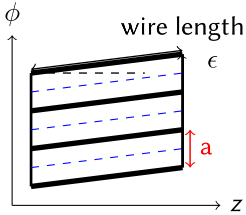
$$\phi = \arctan(y_{hit}/x_{hit}) \quad (2)$$

- The angle between the hit position and the wire detecting it is calculated:

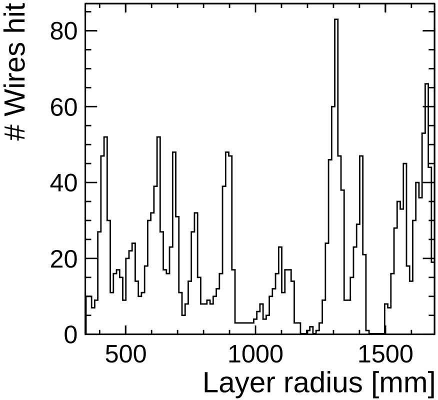
$$\alpha = 2\arcsin(\frac{z_{hit} tan(\epsilon)}{2R}) \quad (3)$$

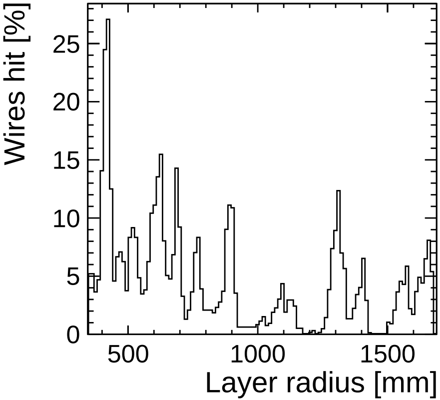
- Total hit azimuthal angle: $\phi + \alpha$





Impact of incoherent pairs in the DCH: work in progress





Secondary vertices produced