Trajectométrie FCC-ee

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The big picture

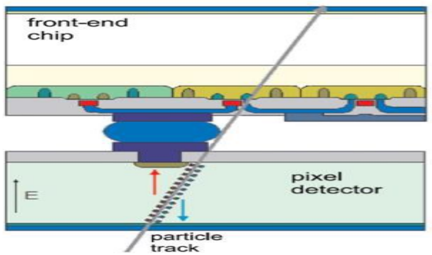
- Tracking/vertexing should deliver outstanding precision for measurement of the track momentum
  - $\sigma(p_T)/p_T \simeq 10^{-3}$ for the Central tracking
- impact parameter resolution should exceed by at least a factor five that typically achieved at LHC experiments.
  - $\sigma(d_0)/d_0 \simeq$ 2/5/20 μm (100/10/1 GeV @ 90°) in the vertex detecteur
- Precision measurements
  - For the innermost vertex layers : target hit resolution of approximately 3 μm together with a material budget of around 0.2% of a radiation length per layer
- The technological solution could be silicon- or gaseous-based tracking
  - Careful choice of a low-mass cooling technology, and a stable, low-mass mechanical structure.
  - in both cases : optimising the material budget
  - particle identification capability would be an advantage.
- Depending on the global design, an additional silicon tracking layer could be added at the outer radius of the tracker to provide a final precise point contributing to the momentum or possibly time-of-flight measurement.
- Current developments : monolithic and hybrid silicon technology, as well as advanced *gaseous tracking developments*

Two configurations of Si-sensor

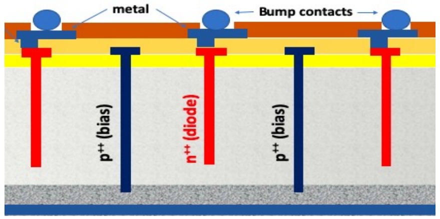
Hybrid design

electronics bumped or wire bonded to Si-sensor
highest rates & radiation tolerance

planar sensors



3D sensors



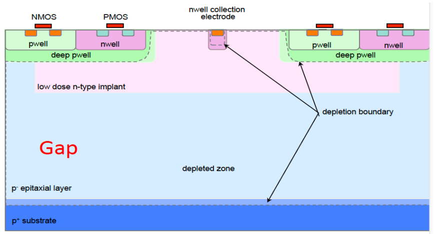
State of the Art

100 to 500 µm thickness in 6″ to 8″ sensor wafers down to
VD: pixel 25 x 25 µm^2 (bump bonding very challenging)
CT: strip pitch > 50 µm O(10) cm long
2 x 10^{16} neq/cm^2 NIEL (Fluence) and 5 MGray TID

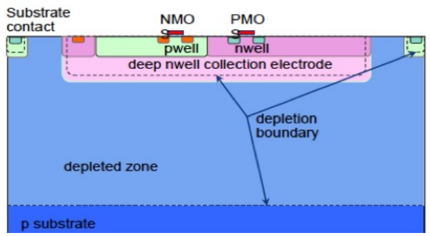
Monolithic Active Pixels

single CMOS imaging process
thinnest, highest granularity

small electrode



large electrode



State of the Art

50 µm thickness, small chips 4 x 4 cm^2
VD: pixel pitch down to 10 µm^2
also up to O(1) mm^2 pitch in large electrode design
2 x 10^{15} neq/cm^2 NIEL (Fluence) and 1 MGray TID

Occupancy

- physics rates of up to 100 kHz + backgrounds driven by synchrotron radiation and incoherent pair production.
- At 365 GeV operation
  - beams are separated by 994 ns
  - the occupancies in the barrel vertex detector, can reach 0.04 hits per mm^2 per bunch crossing at the innermost layer.
  - Taking into account an expected pixel pitch of approximately 25µm, a cluster multiplicity of 5 and a safety factor of 3 gives an occupancy of the vertex detector still below the level of 10^{-3} .
- Operating at the Z
  - backgrounds are lower;
  - however, the bunch separation of 20 ns combined with an expected detector time integration window of around 1 µs yields similar occupancies.

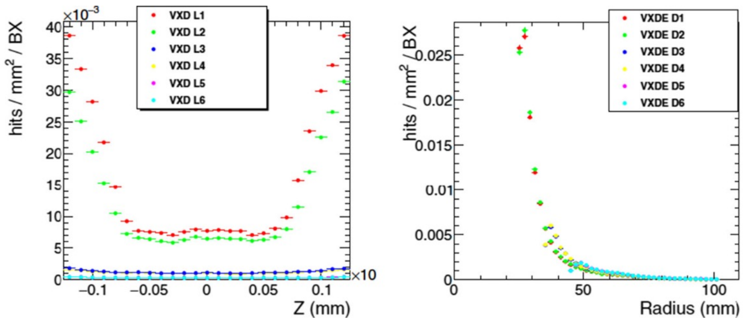
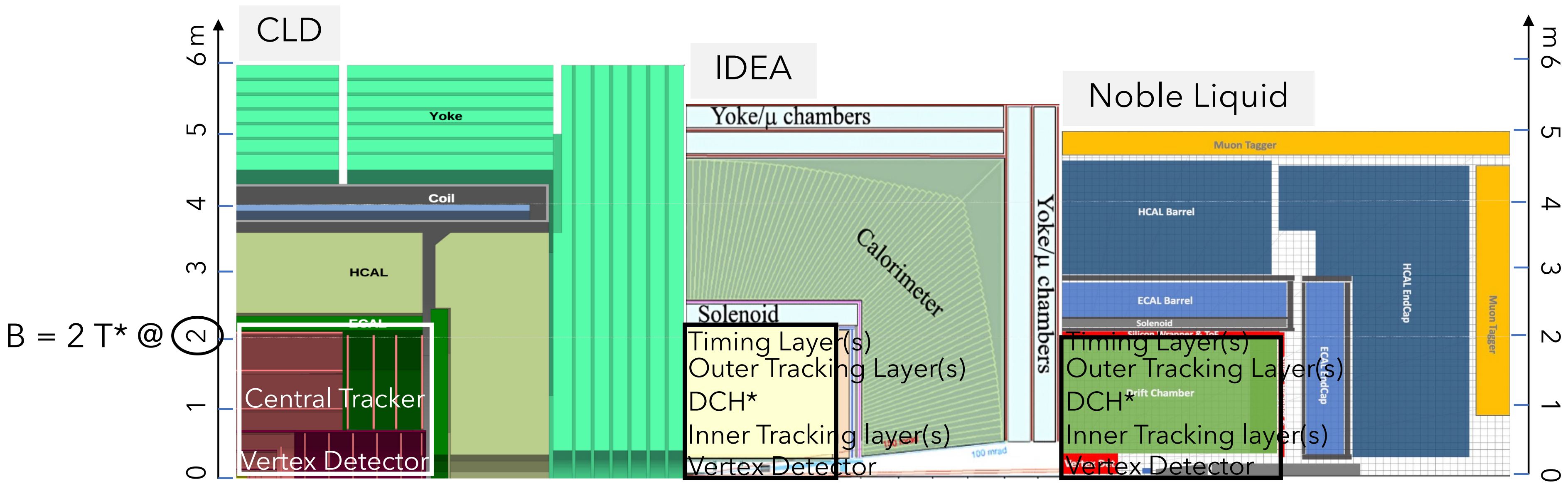


Fig. 3 Expected occupancy in the barrel and forward regions of the vertex detector, driven by incoherent pair creation [11]

https://doi.org/10.1140/epjst/e2019-900045-4

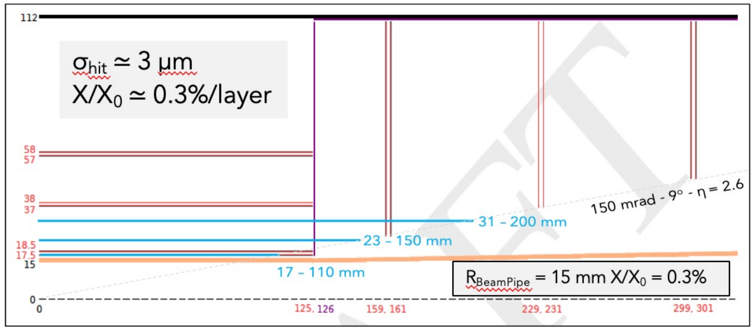
Detector Concepts

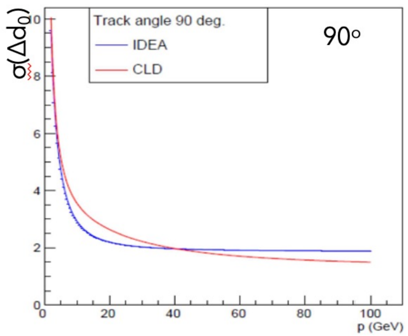


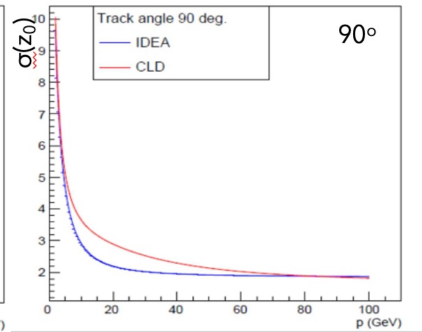
Inner Vertex

MAPS technology to achieve position precision and transparency
configurations can be different but performance should be similar*

CLD double layers in barrel and endcap disks and IDEA double closer layers in Long Barrel (on top of each others)



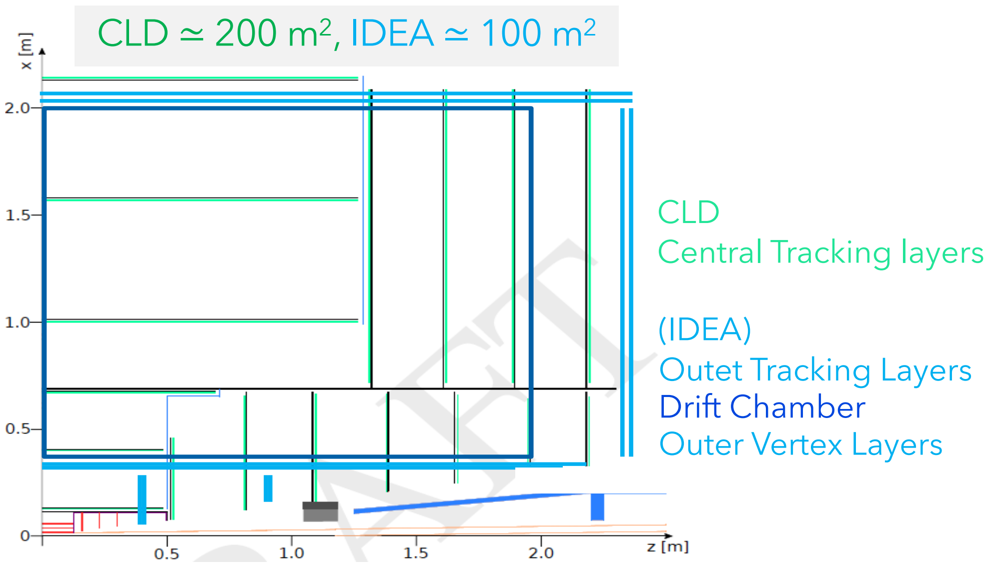


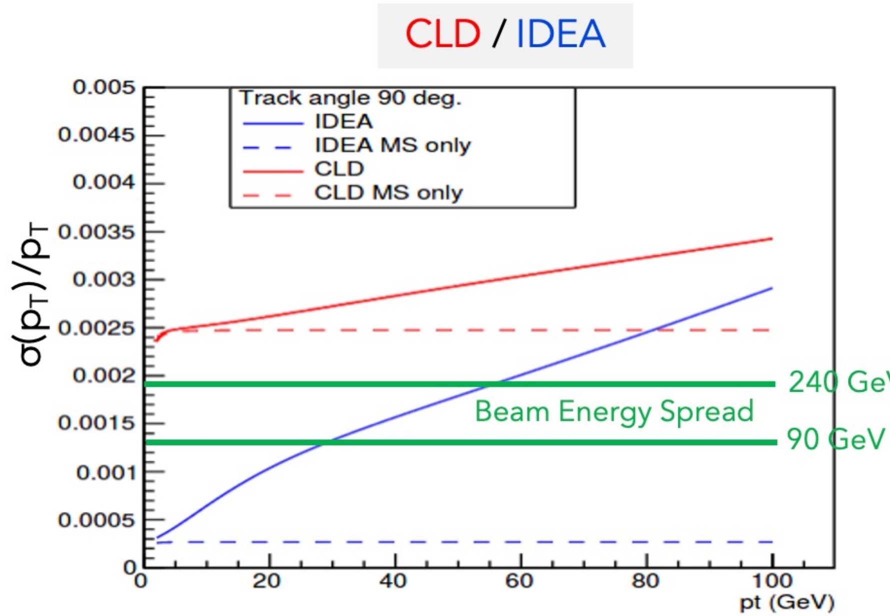


to be scaled to new BP radius of 10 mm

- CLD : 3 double layers/disks in Barrel/Endcaps
- IDEA : 3 single closer layers in Long Barrel
  - resolution 3 µm - $X/X_0 \simeq$ (2 x) 0.3 - 0.25 % / layer
  - $r_{BeamPipe}$ = 1 cm - X/X_0 = 0.3%

Central tracking (CT)





CLD : 6 layers and 9 disks

IDEA : 1-2 layers surrounding DCH

- ball park 5-7 μm resolution & 1 – 2 % X/X_0 inside-out

Caracteristiques CLD

- full silicon concept with double layers of sensors on a common supporting carbon fibre structure for full coverage.
  - 3 double layers of silicon pixel sensors and 3 double discs for the vertex detector
  - 3 double layers of short strips sensors
  - 7 forward double discs for the innermost tracking volume
  - 3 double layers and 4 double discs for the outer tracking
- The vertex detector :
  - sensors with 25 × 25 μm^2 pixels
  - an effective thickness of 50 µm,
  - an estimated total radiation length including cooling of 0.3% per single layer
  - active area of about 0.35 m^2 .
- Tracking region
  - sensor 200 µm thick with 50 µm × 1 mm to 10 mm long strips with the innermost double disc pixelated, similarly to the vertex detector.
  - Estimated radiation length is 1% per layer for the region of the sensors, coolant and mechanical structure, and a further 2.5% for the main cooling distribution pipes, main mechanical supports and cables.
  - Active area is about 196 m 2 .

Caracteristiques Idea

- Idea :
  - The vertex detector currently considered is based on active monolithic pixel sensor technology
    - The target performance would be a resolution of a few microns with a total material of 0.15% - 0.3% X0 per layer and power dissipation around 20 mW/cm 2 in order to avoid the need for active cooling
  - Very light central drift chamber
    - lower mass than silicon-based tracking
    - provide better momentum resolution over the range of interest
  - timing information to the wires
    - possibility to count individual ionising events of the traversing track and dE/dx information (particle identification) – o(10)ps

Summary comparison of today's requirements including operation conditions

			ALICE 3	FCC-ee
Vertex Detector[3]	MAPS Planar/3D/Passive CMOS LGADs	Position precision (μm)	2.5	3
		X/X_0 (%/layer)	0.1	0.1
		Power (mW/cm^2)	70	tbd
		Rates (MHz/cm^2)	100	50
		Wafer are (cm^2)	25 x 10	tbd
		Time bin/precision (μs)	0.5/0.1	1
		NIEL (1 eV neq/cm^2)	1 x 10^{16}	?
		TID (rad)	300 x 10^6	?
Tracker[6]	MAPS Planar/3D/Passive CMOS LGADs	Position precision (μm)	10	7
		X/X_0 (%/layer)	1	1
		Power (mW/cm^2)	20	tbd
		Rates (kHz/cm^2)	1 - 5	
		Wafer are (cm^2)	2.6 x 3.2	tbd
		Time bin/precision (μs)	0.5/0.1	1
		NIEL (1 MeV neq/cm^2)	5 x 10^9	
		TID (rad)	1.5 x 10^2	
Time of Flight[8]	MAPS Planar/3D/Passive CMOS LGADs	Timing precision (ps)	20	tbd
		Granularity (mm)	1 x 1 5 x 5	
		Power (mW/cm^2)	50	tbd
		Rates (kHz/cm^2)	74/4/120	
		NIEL (x 10^{11} neq/cm^2)	2 x 10^{11}	
		TID (rad)	7 x 10^3	

Most constraining conditions in VD

- Maximum rates have same scale in ALICE-3 and FCC-ee
- Integration time have same scale in ALICE-3 and FCC-ee
- NIEL and TID likely more constraining in ALICE3

➢ Work in progress in MDI to reassess FCC-ee conditions with more realistic simulations (A. Ciarma's presentations)

Power consumptions*

- VD ≃ 70 mW/cm^2, CT ≃ 20 mW/cm^2 ALICE-3
- TL ≃ 50 mW/cm^2 (ARCADIA)

➢ Slightly less constraining conditions at FCC-ee may help, a priori similar model for architecture ?

Radiation tolerance

- should be within SoA MCMOS technology limit assuming operation at -25° temperature

** Depending on channel density, timing precision, rates, technology, RO architecture, sensor size through power distribution*

Quelques mots sur FCCSW

- Documentation- tutoriaux – hands-on sessions
  - http://hep-fcc.github.io/FCCSW/
- Distribué sur cvmfs
- source /cvmfs/sw.hsf.org/key4hep/setup.sh
  - Is doing everything for you
    - Ou presque…
- Et apres ..
  - Prend du temps (semaines/mois) pour avoir un workflow (gen-sim-local-reco-reco…) qui tourne
  - Quelques instabilités parfois
  - Petite communauté de core developers/maintainers
    - CERN
    - Mais repond aux questions/meetings informels reguliers
  - Beaucoup de choses toujours à developper
    - E.g local reconstruction

Documentation computing

- **Offline Computing resources for FCC-ee and related challenges**
  - https://arxiv.org/abs/2111.10094
  - Timing dominated by simulation
    - Reconstruction: events less busy than LHC/HL-LHC, however precision needed

Table 2. Typical RAW event sizes in kB for the **Z** run for the two baseline detector solutions [12] and the ALEPH detector [13]; the contribution of the final states originating from the Z exchange (Z decays) is singled out from the expected total (all events).

	CLD		IDEA		ALEPH	
Readout channels	1.9 G		2.8 G		1 M	
Sub-detector	Z decays	all events	Z decays	all events	Z decays	all events
Vertex	1.3 kB	62 kB	1.3 kB	62 kB		
Tracker	1.4 kB	102 kB	500 kB	595 kB		
Calorimeter	230 kB	920 kB (*)	500 kB	2000 kB (*)		
Muon	0.03 kB	0.75 kB	0.03 kB	0.75 kB		
Total	233 kB	1085 kB	1001 kB	2658 kB	120 kB	550 kB

(*) For the calorimeters, reference [12] does specify numbers for the all events case, only for the IDEA pre-shower; the numbers are obtained by applying the same factor 4 expected for the IDEA pre-shower to all the calorimeters.

Momentum and Impact Parameter Resolution Performance

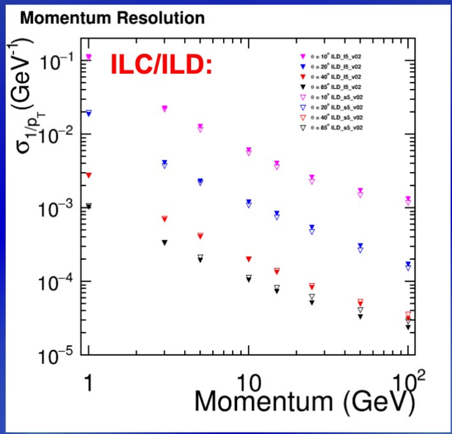
Track momentum resolution:

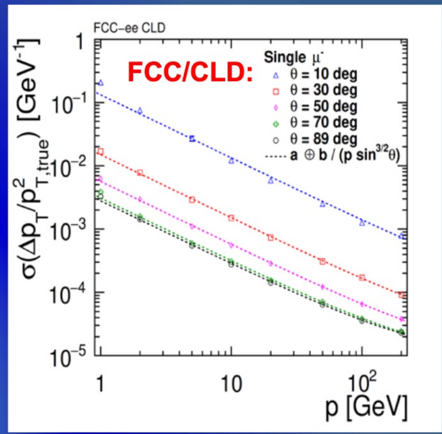
$$\sigma(\Delta p_T/p_T^2) = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

track radius measurement — multiple scattering

- P_T resolution @ 100 GeV ≈2-3 x 10−5 GeV−2 for both ILD & CLD (single muons)

- ILD-S/ILD-L both meet asymptotic momentum resolution goal





arXiv: 2003.01116

arXiv: 1911.12230

Impact parameter resolution:

$$\sigma(d_0) = \sqrt{a^2 + b^2 \cdot \mathrm{GeV}^2/(p^2 \sin^3(\theta))}.$$

- σ(d0) resolution is affected by the layout of vertex detector and single point resolution

- Single point resolution has a large impact (50%) on σ(d0) at high p_T (CLD study, similar for CEPC)