Design and Performance of the IDEA Vertex Detector at FCC-ee in Full Simulation

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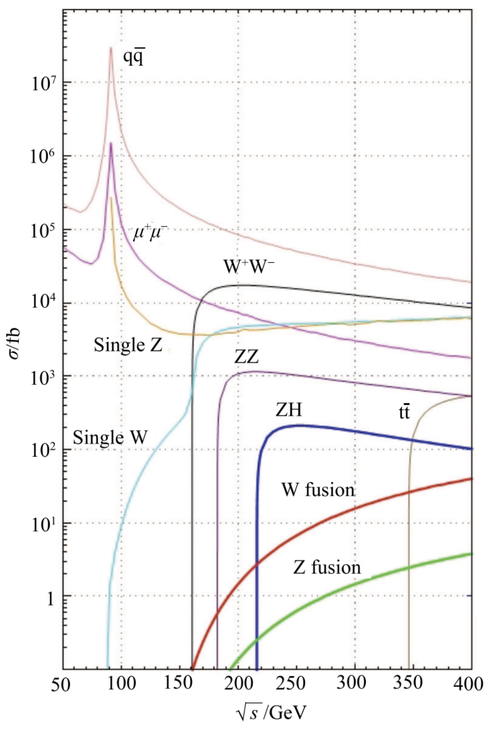
The particle physics community is preparing for the post-LHC era by investigating the feasibility of the *Future Circular Collider* (FCC, [1]): a 90.6 km circumference collider to serve particle physics until the end of the 21st century. *FCC-ee* will produce intense e^+e^- collisions at energies of 90–365 GeV, making it an EW, Higgs and top factory. Later, the FCC is equipped with 14–20 T magnets to collide hadrons with energies of 80–116 TeV (*FCC-hh*).

Physics programme at FCC-ee experiments



Annihilation cross sections in e^+e^- collisions. Adapted from [2].

EW: $6 \cdot 10^{12}$ Z, $2.4 \cdot 10^8$ WW, $1.9 \cdot 10^6$ $t\bar{t}$
- 20–50 or more improvement in electroweak quantities
- Indirect sensitivity to new particles up to 10–70 TeV

Higgs: $1.78 \cdot 10^6$ HZ, 125k WW $\rightarrow$ H
- Higgs width at 1.6%
- Higgs couplings at percent to sub-percent precision

Flavour: $O(10^{12})$ $b\bar{b}$ and $c\bar{c}$, $O(10^{11})$ $\tau\bar{\tau}$
- $\sim$ 10 more than Belle-II, not limited to $m(\Upsilon(4S))$

And many many more!

FCC-ee detector requirements

e^+ and e^- are **point-like particles** $\rightarrow$ very different than the LHC!
- Initial E and p known
- Almost no pile-up, no QCD background

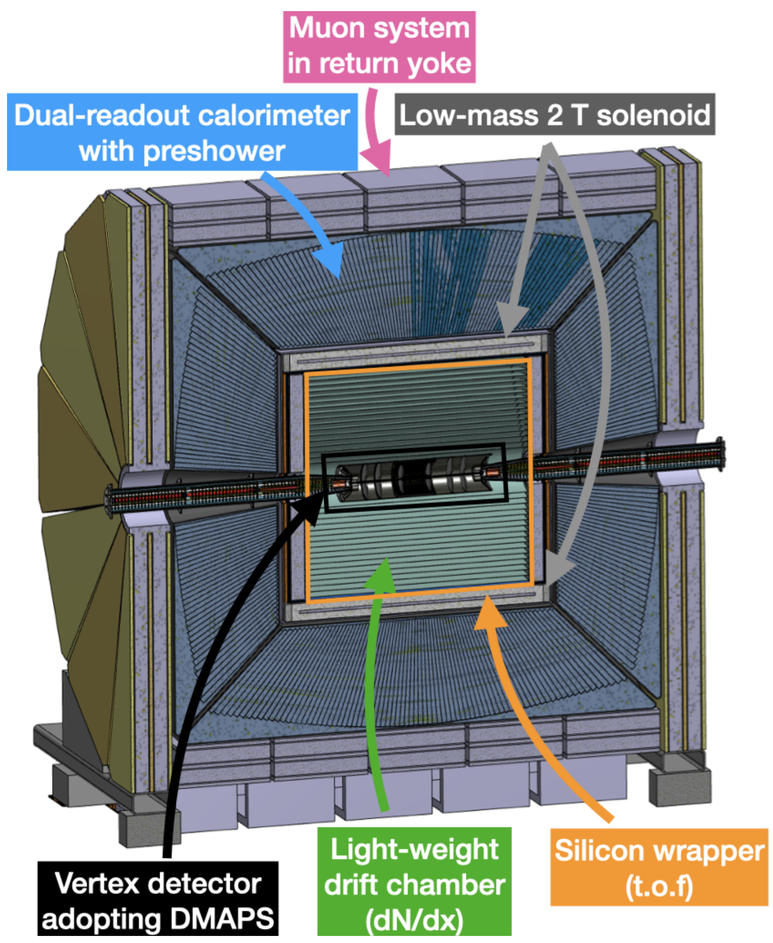
FCC-ee running at the Z pole ($\sqrt{s} = 91.2$ GeV) generates extremely large statistics (*tera-Z factory*).To benefit from this, the systematic uncertainties need to be kept down to 10^{-4}–10^{-5}
$\rightarrow$ **Stringent requirements on FCC-ee detectors**!

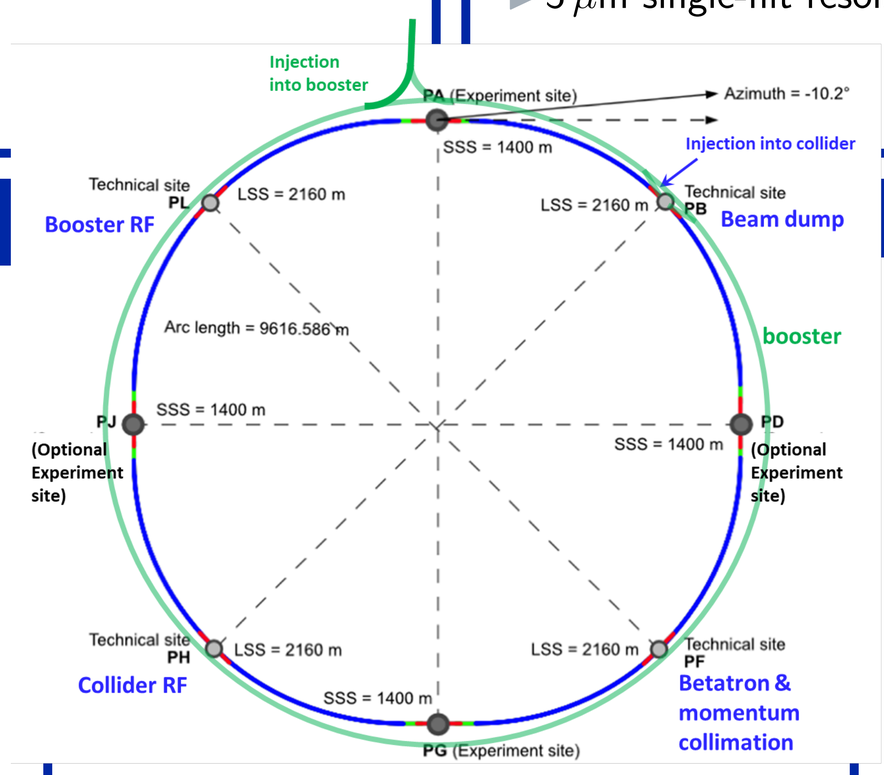
Vertex detector to determine the spatial locations of the interactions
- Efficient flavour tagging (b/c/g/**s**)
- Precise flight distance measurements

Vertex detector requirements:
- 3 μm single-hit resolution
- Limit material budget (X/X_0) to $\simeq$ 0.3% per inner layer

$\rightarrow$ $\sigma_{p_T}/p_T^2 \simeq 2 \cdot 10^{-5}$/GeV in tracker

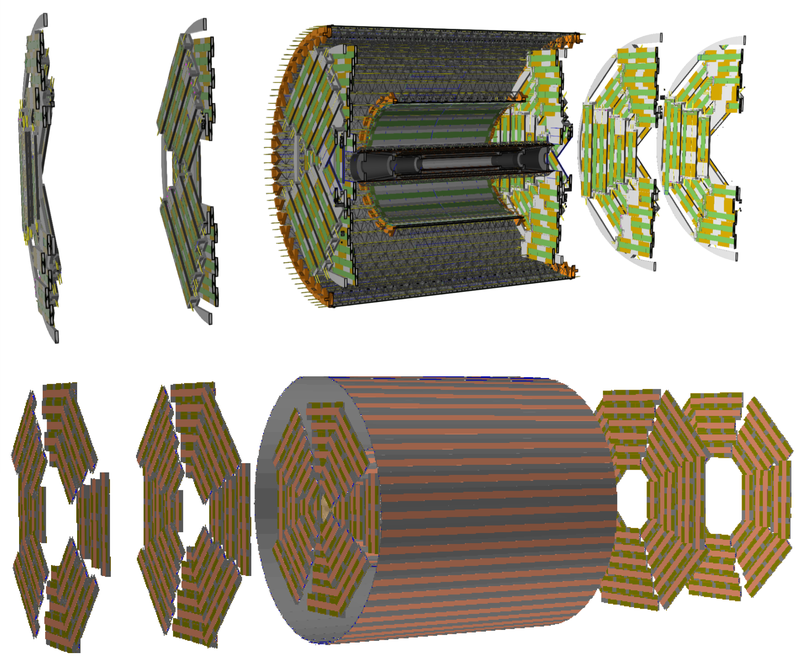
The IDEA detector concept for FCC-ee





Latest FCC-ee accelerator layout with four interaction pionts [5]

...and its vertex detector in full simulation



CAD design (top, from F. Palla, F. Bosi) and DD4hep implementation (bottom)

- Much higher level of detail than other vertex detector implementations
- Can check for cracks in coverage and assess vertexing performance realistically

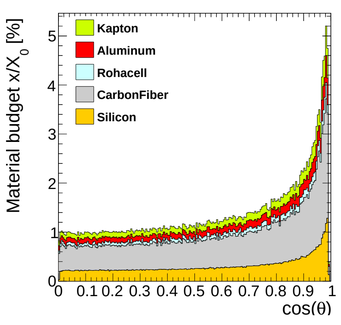
Common software vision: Key4hep

- Adopted by all future collider projects
- From generator to analysis
- EDM4hep+DD4hep+Gaudi

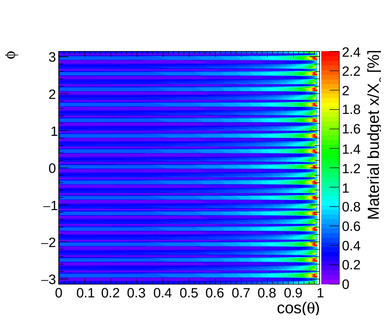
Enabling plug-and-play functionality and interface with accelerator components

Prospects of wafer-scale DMAPS for FCC-ee vertex detectors

Depleted monolithic active pixel sensors foreseen for vertex detector by all e^+e^- detector proposals
- Sensor and readout in one silicon die



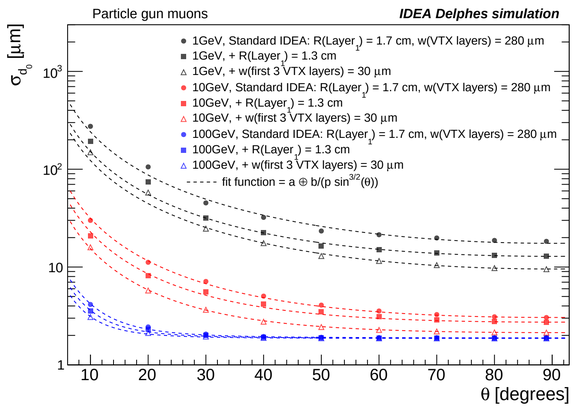
Vertex inner barrel material budget



Vertex first layer material budget

Sensor is only small fraction of total X/X_0 $\rightarrow$ Improve tracking and vertexing performance by minimising support and readout material
$\rightarrow$ **Wafer-scale curved sensors in 65 nm for ALICE ITS3**
- One sensor per half-layer only
- Self-supporting, air cooled

$\rightarrow$ Basically only silicon in vertex



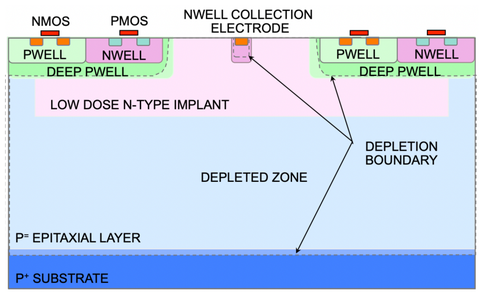
Effect of reduced material budget on d_0 resolution in Delphes fast simulation, L. Freitag (BSc. thesis [3])

R&D on 65 nm DMAPS at UZH

Joined team of ALICE ITS3, CERN R&D and other institutes!

Analog pixel test structure (APTS)
- 16 pixels, 10 to 25 μm pitch
- Analogue readout, different processes
- Different p-well and n-well designs on single test structure (multiplexer)

$\rightarrow$ Test beam (three weeks ago), lab tests with Fe-55 source and X-ray tube

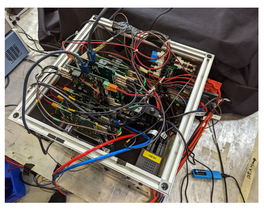


TPSCo 65 nm modified process with gap [4]

Circuit Exploratoire (CE-65)
- 64x32/48x32 pixels, 15/25 μm pitch
- Digital readout

$\rightarrow$ Fe-55 source for pixel-by-pixel calibration, test beam in September

Fe-55 test setup



ALPIDE telescope

Goal:
- Development and optimisation towards FCC-ee vertex detectors
- Sensor perf. $\leftrightarrow$ Vertex perf. $\leftrightarrow$ physics perf. $\leftrightarrow$ sensor spec.

[1] FCC Collaboration, *FCC-ee: The Lepton Collider*, The European Physical Journal Special Topics **228** (2019) 261–623.
[2] X. Mo, G. Li, M.-Q. Ruan, and X.-C. Lou, *Physics cross sections and event generation of e^+e^- annihilations at the CEPC*, Chinese Physics C **40** (2016) 033001.
[3] L. Freitag, *Benefits of Minimizing the Vertex Detector Material Budget at the FCC-ee*, 2023. BSc thesis, presented 01 Feb 2023.
[4] W. Snoeys, et al., *Optimization of a 65 nm CMOS imaging process for monolithic CMOS sensors for high energy physics*, in *Proceedings of Pixel2022*.
[5] M. Benedikt, *FCC Feasibility Study Status, layout by K. Oide, M. Hofer, et al.*, 06, 2023. FCC Week 2023.

EPS-HEP 2023
Universität Hamburg
Hamburg, Germany
20-25. August 2023