Pixel Sensors for FCC Vertex Detectors

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FUTURE CIRCULAR COLLIDER

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In 2012, the last missing piece of the Standard Model (SM) of particle physics, the Higgs boson, was discovered at the Large Hadron Collider (LHC) at CERN in Geneva. Since then, the LHC greatly improved our understanding of the elementary particles of nature and their interactions. The LHC is scheduled to operate until the late 2030's and the particle physics community is now planning for the post-LHC era.

Future Circular Collider project

The FCC study [1] envisions a new ~ 100 km long circular collider ring to test the limits of the SM to an unprecedented level. In a first stage, intense collisions of electrons and positrons are produced (FCC-ee). Collision energies of 90–365 GeV at instantaneous luminosities of up to $230 \cdot 10^{34}\,\mathrm{cm^{-2}s^{-1}}$ make the FCC-ee an electroweak (EW), Higgs and top factory. This for example allows the precise study of the Higgs boson properties and to investigate hints of lepton flavour violation (LFV) recently observed. In the second stage, the FCC would be equipped with 16 T strong magnets to collide hadrons with energies up to 100 TeV (FCC-hh), a more than seven fold increase from the LHC.

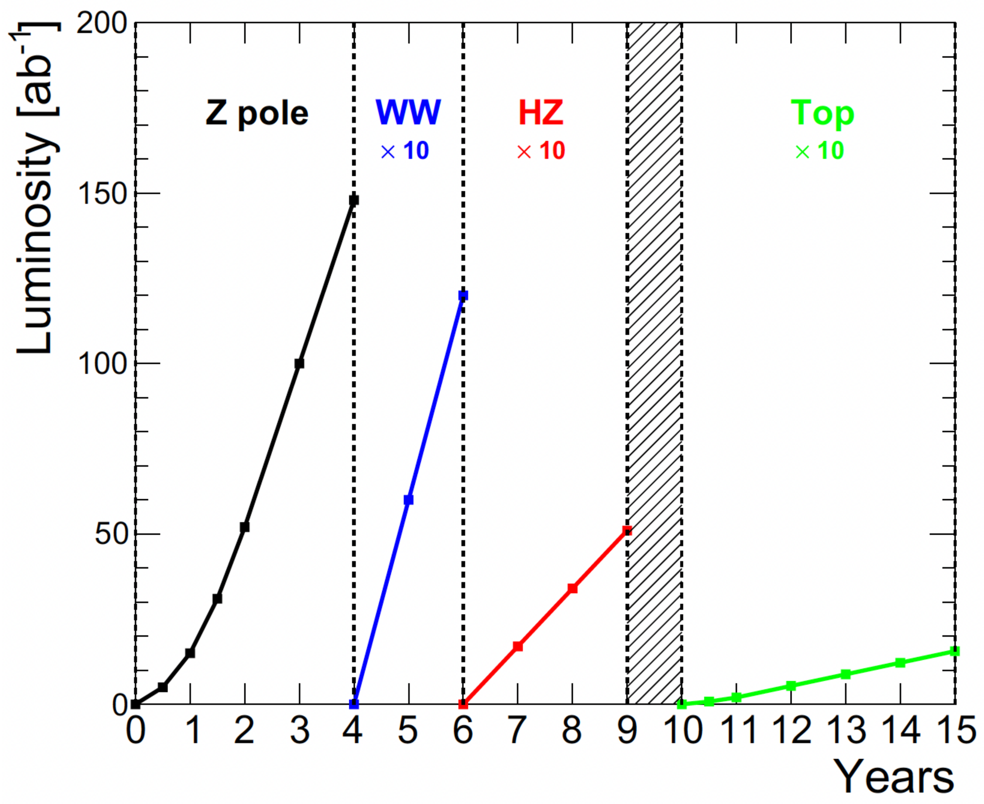

Figure 1: FCC-ee is operated at energies of around 90, 160, 240 and 350–365 GeV [1].

FCC location

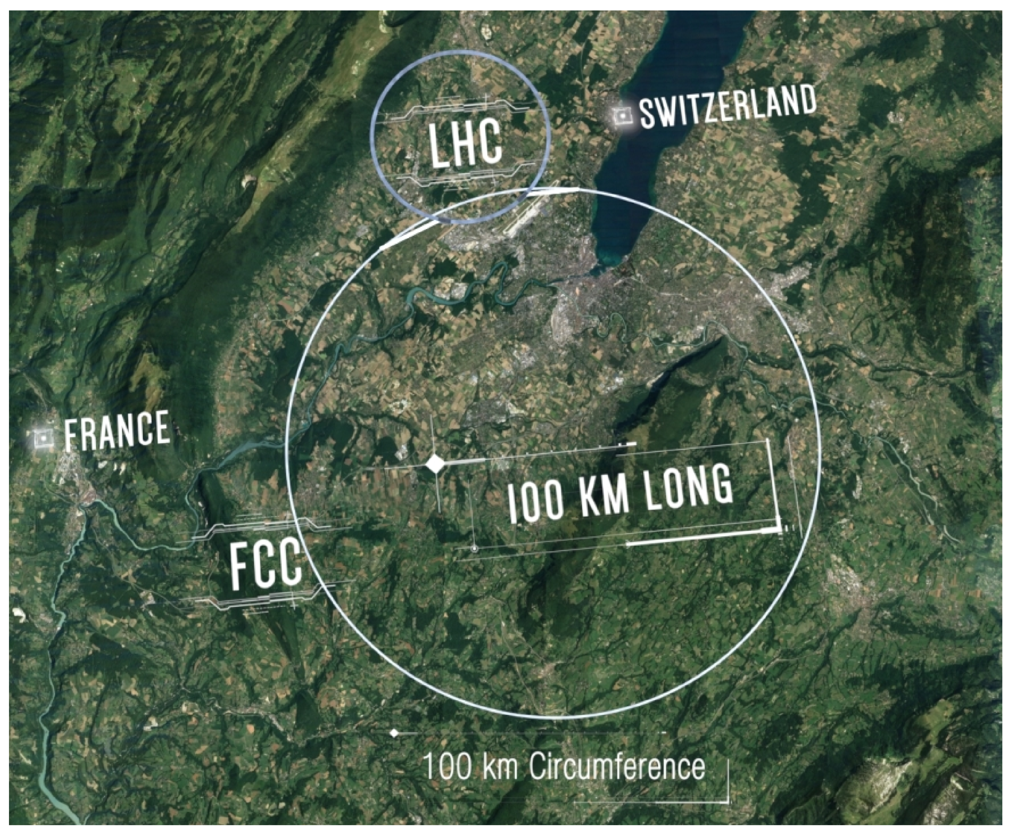

Figure 2: FCC Study@CERN

Physics program at FCC-ee experiments

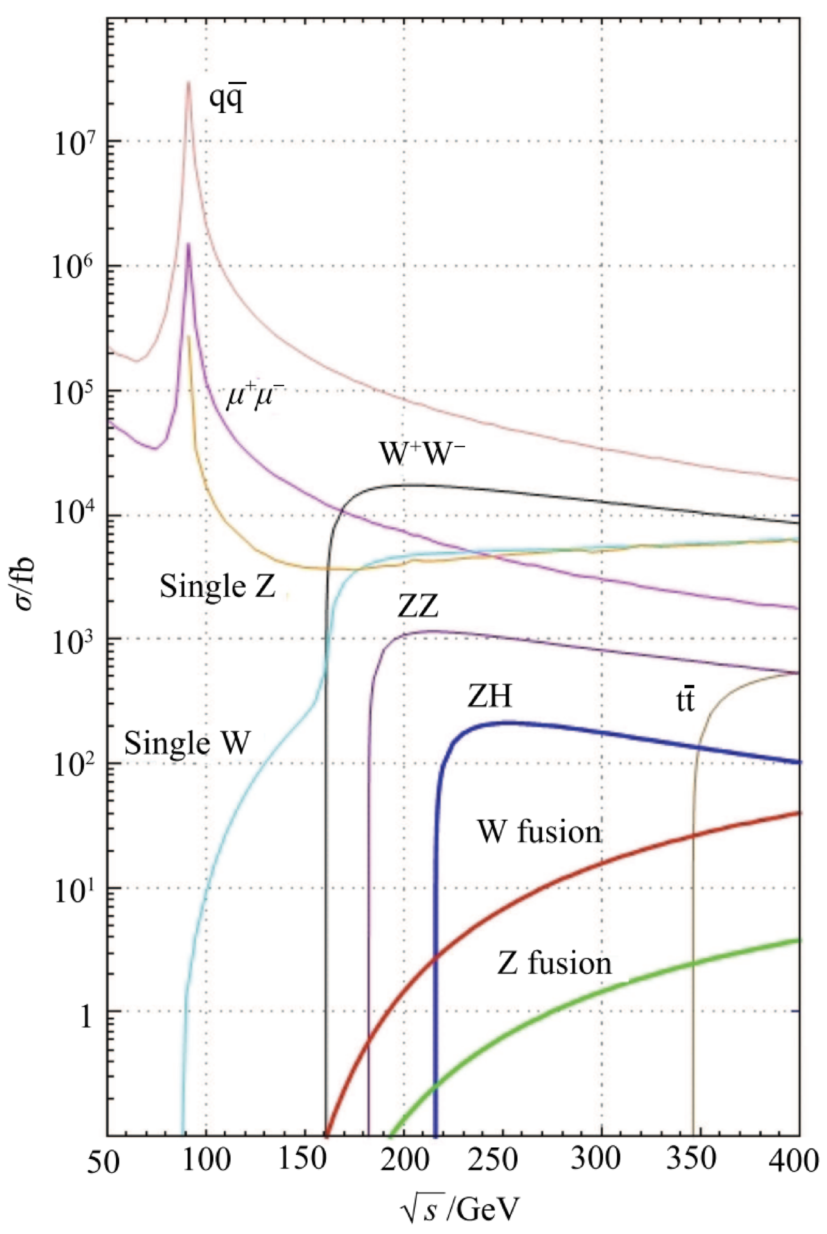

Figure 3: Annihilation cross sections in e^+e^- collisions. Adapted from [2].

EW: $5 \cdot 10^{12}$ Z, 10^8 WW, 10^6 $t\bar{t}$

- 20–50 or more improvement in electroweak quantities [3]
- Indirect sensitivity to new particles up to 10–70 TeV [1]

Higgs: $1.2 \cdot 10^6$ HZ, 75k WW → H

- Higgs width at 1.6% [1]
- Higgs couplings at percent to sub-percent precision

Flavour: 10^{12} $b\bar{b}$ and $c\bar{c}$, $1.7 \cdot 10^{11}$ $\tau\tau$

- LFV and flavour anomaly searches

And many many more!

FCC-ee detector requirements

e^+ and e^- are **point-like particles** → 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}

→ **Stringent requirements on FCC-ee detectors**:

- Luminosity measurements down to 10^{-4}
- Error on detector acceptance to $\sim 10^{-5}$
- Efficient flavour tagging (b/c/g/s?) and particle identification (π/K/p)

For the **vertex detector**, determining the spatial locations of the interactions, this requires:

- Precise vertex determination → $O(3 \times 3\,\mu\mathrm{m}^2)$ single-hit resolution
- Maximise momentum resolution → Minimise material in the vertex detector to limit multiple scattering ($X_0 \sim 0.3\%$ per layer)

Depleted Monolithic Active Pixel Sensors (DMAPS)

Monolithic: Signal generation, amplification and readout in one die

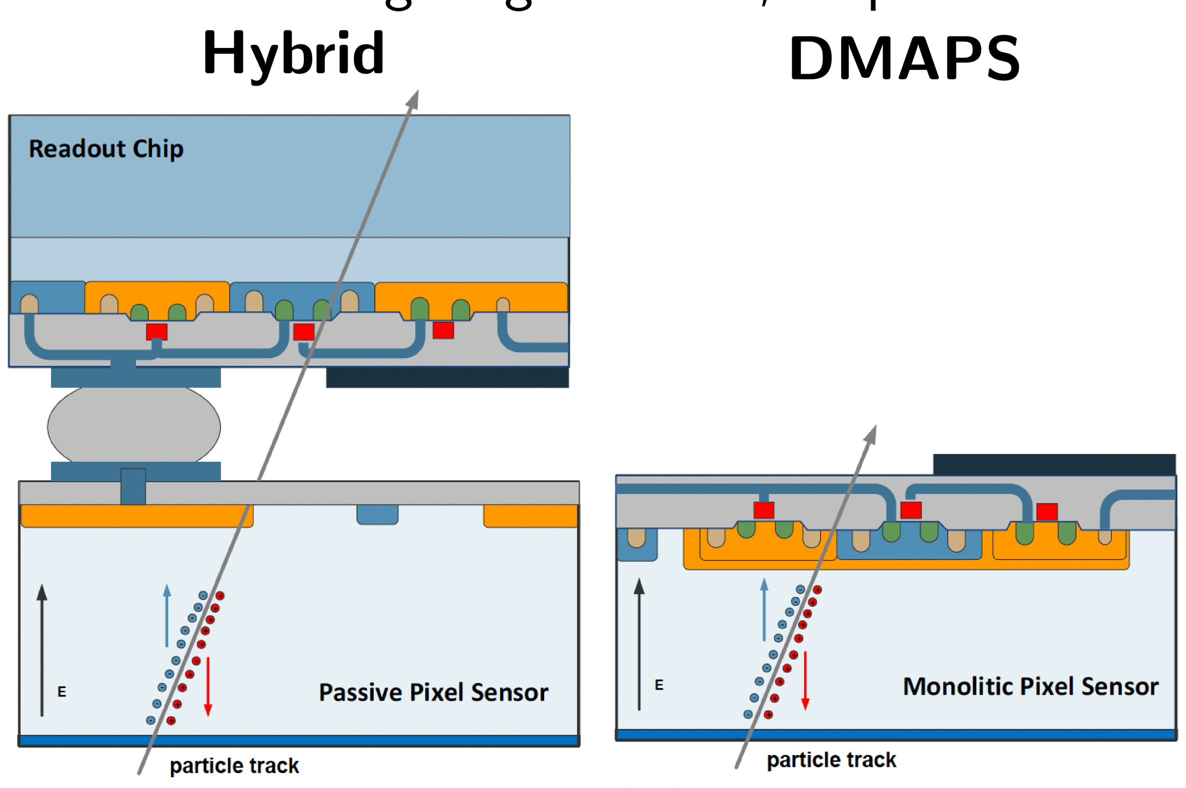

Figure 4: Comparison between hybrid and depleted monolithic active pixel sensors [4].

- Scalable to (very) large sensors
- **Less material** (possibly no support material)
- Simpler assembly
- More cost effective

Depleted: p-n junction to create volume free of space charge
→ Collect induced charge by drift → fast!

Best candidate for FCC-ee vertex detector

Possible thesis topics

Hardware work

- Lab characterisation of DMAPS test structures:
  Fumble with oscilloscopes, cables and lasers!

Physics performance case study

- Data analysis of simulated FCC-ee collisions to assess potential reach in benchmark physics processes
  Study process in question, apply selections and plot the results!

Detector performance simulation

- Estimate the impact of different detector designs on vertexing and tracking performance
  Change detector parameters, simulate collisions, estimate performance metrics and compare!

Your ideas!

- We are open to other contributions related to FCC-ee

[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] FCC Collaboration, *FCC Physics Opportunities*, The European Physical Journal C **79** (2019).

[4] T. Hemperek, *Advances in pixel detectors*, 9, 2021. PSD 2021 workshop.

Open Day 2021
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