CLIC-Inspired Detector for FCC-ee

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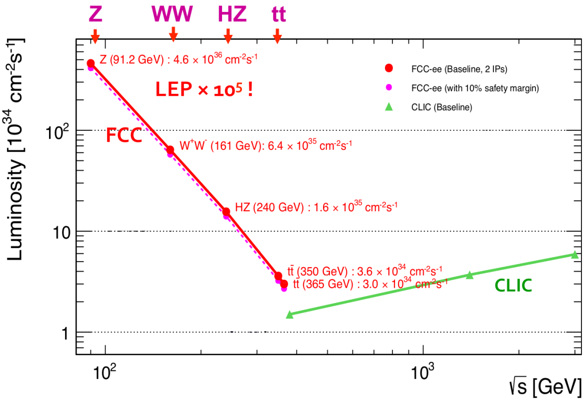
- FCC-ee is a high-luminosity, high-precision e^+e^- circular collider with four operational energy regimes: Z, WW, HZ, tt.
- Fixed 100 MW Synchrotron Radiation (SR) at all energies $\rightarrow$ Larger beam currents possible at lower energies
- High statistical accuracies $\rightarrow$ Small experimental uncertainties are needed $\rightarrow$ Demands state-of-the-art performance for all detector subsystems
- This presentation will cover one of the proposed detector designs for FCC-ee which is based on the detector proposal for CLIC



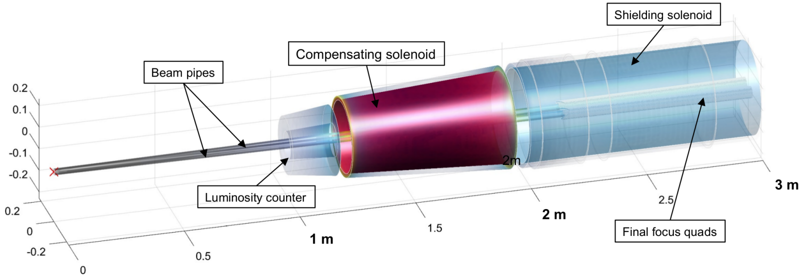
	Beam Energy [GeV]	Luminosity [10^{34} cm^{-2}s^{-1}]
Z	45.6	230
WW	80	32
HZ	120	7.8
tt	182.5	1.5

	Bunch intensity [10^{11}]	Bunch spacing [ns]
Z	1.7	20
WW	1.5	166
HZ	1.5	846
tt	2.8	8533

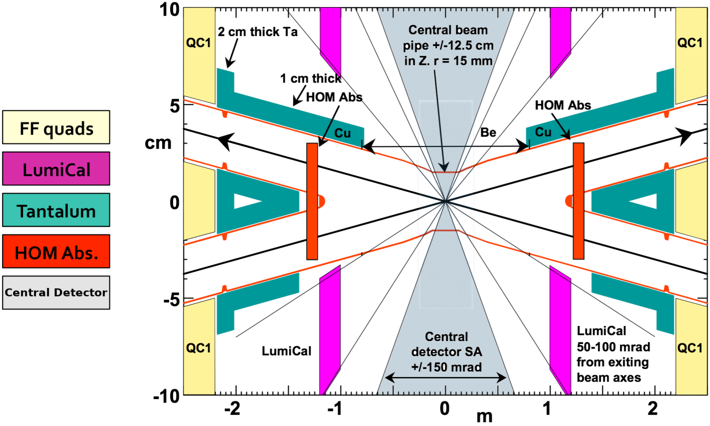
Detector Design

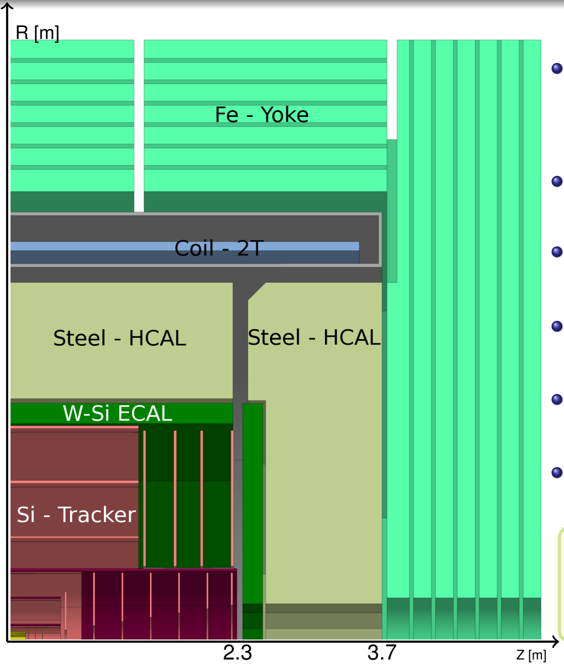
Detector Constraints from the Machine Design

- In order to maximize luminosity final focusing quadrupole chosen to be at 2.2m from IP - **inside the detector**
- Compensating solenoid to prevent emittance blow-up from detector magnetic field due to non-zero crossing angle is even closer to the IP
- Constrains **the maximum possible detector magnetic field to 2T** (while the CLIC proposal assumes 4T magnetic field)



- Central detector has to be fitted within $\pm$150mrad $\rightarrow$ constrains forward region
- Luminosity monitor (LumiCal) is inside MDI region
- Additional tantalum shielding is foreseen to suppress synchrotron radiation background in the innermost layers of the detector (see picture)





- Full silicon VTX and Tracker:
  - $\geqslant$12 hits per track
  - $r_{inner} = 17$mm, $r_{outer} = 2.1$m
    $r_{inner} = 31$mm, $r_{outer} = 1.5$m - CLIC
- W-Si ECAL
  - 40 layers, 22 X_0
- Fe-Scint HCAL
  - 44 layers, 5.5 λ_I
- 2 Tesla magnetic field, Coil is outside of the calorimeter
- Steel return yoke with 6 RPC muon chambers (1.5m thickness)
- MDI (forward region): $<$ 150 mrad, accommodates LumiCal

Detector design inspired by detectors for CLIC and ILC and optimized for FCC-ee conditions

Software

- Dedicated software for FCC-ee is under development.
- For performance study of the CLIC-inspired detector for FCC-ee one can benefit from the fully functional and tested iLCSoft software used by the CLIC and ILC community.

- Detector geometry description and event simulation: DD4hep
- Event Reconstruction: Marlin

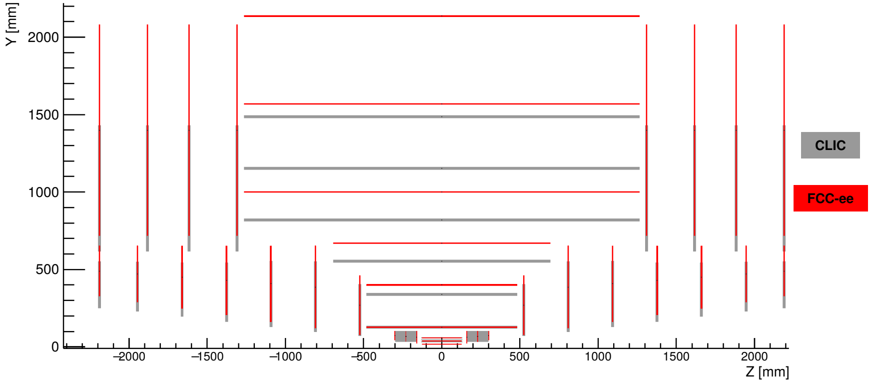
- Track Pattern recognition: TruthTracking or ConformalTracking
- Particle Flow Reconstruction: PandoraPFA

- Detector model:
  https://github.com/iLCSoft/lcgeo/tree/master/FCCee/compact/FCCee_o1_v01

VTX and Tracker Layout

- Tracking system consists of Vertex detector(VTX), Inner and Outer Trackers (IT and OT)
- VTX detector - 3 pixel double layers in barrel and endcap
- Inner and Outer Trackers - 3 barrel layers each and 4-7 disks
- Single-point resolution (sigma): VTX - $3 \times 3\ \mu$m; IT - $7 \times 300 \mu$m; OT - $7 \times 3000 \mu$m
- More than 12 hits per track over theta range 8.6° - 171.4°
- Material budget: 0.2%X0 per VTX layer - has to be revised due to the need for cooling

Comparison of the CLIC and FCC-ee tracking system



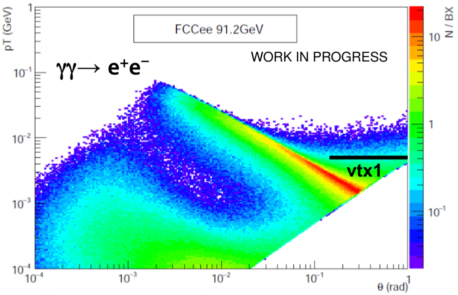
FCC-ee backgrounds

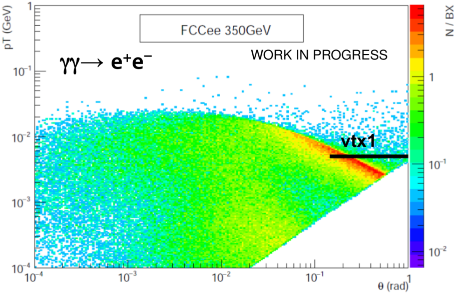
FCC-ee Backgrounds

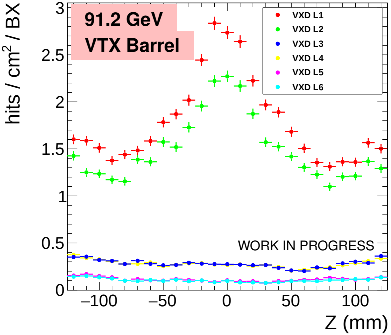
- $\gamma\gamma \to e^+e^-$
- $\gamma\gamma \to$ hadrons
- Synchrotron radiation

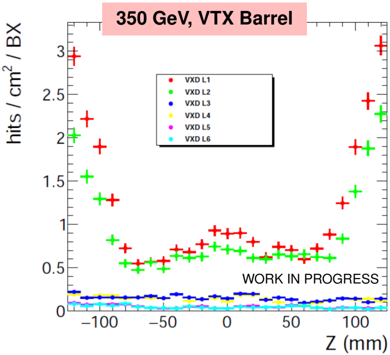
Background Estimation

- Full simulation (GuineaPig, GEANT/DD4hep)
- Detector assumptions:
  - pixel silicon detector, $25\times25\mu m^2$
  - strip detector, 1×0.05 mm^2
  - Cluster multiplicity = 5 for pixels and = 2.5 for strips
- Safety factor: 5
- Occupancy is estimated in the VTX and Tracker detectors









Maximum occupancy per BX

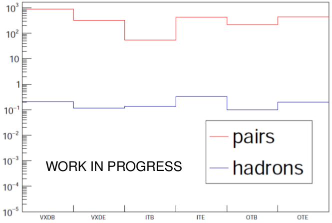
E_{CM}	91.2 GeV	350 GeV
VTX Barrel	0.05 %	0.05 %
VTX Endcap	0.02 %	0.03 %
Tracker B.	0.002 %	0.0025 %
Tracker E.	0.014 %	0.0075 %

- Maximum 0.05% per BX both for 91.2 and 350 GeV cases from $\gamma\gamma \to e^+e^-$ background
- Need ≈0.4 μs read-out time at 91.2 GeV, to limit the occupancy to 1%
- Study at 365 GeV center-of-mass energy is ongoing. Preliminary results are of similar size as for 350 GeV case

Background Estimate

Estimate of $\gamma\gamma \to$ hadrons bkg.

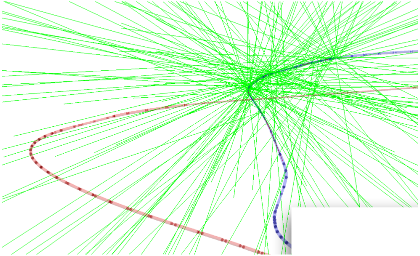
Hits per BX per subdetector at 91.2 GeV



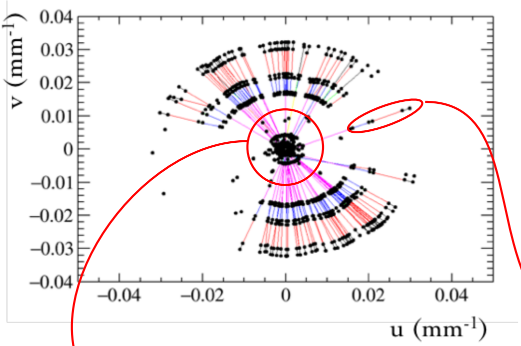
- Size of $\gamma\gamma \to$ hadrons background is **2 orders of magnitude lower** than from $\gamma\gamma \to e^+e^- \to$ negligable effect

Synchrotron radiation

- Study is ongoing
- Preliminary results show negligable effect for 91.2 GeV case and comparable effect to $\gamma\gamma \to e^+e^-$ for 350/365 GeV cases



Tracking and Calorimetry Performance



Hits from the Vertex

Hits from the Tracker

Track fitting is done in the conformal space:

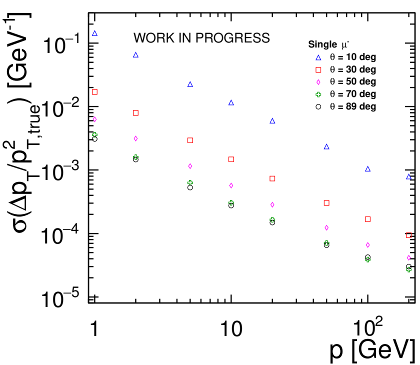
$$u = \frac{x}{x^2 + y^2} \qquad v = \frac{y}{x^2 + y^2}$$

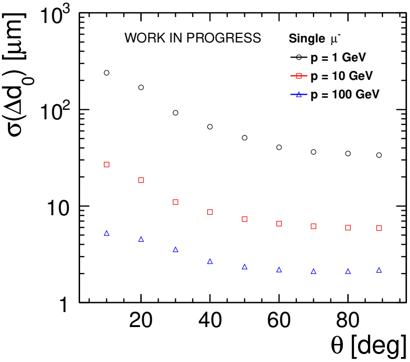
Cellular automaton is used to perform straight line search

- Conformal tracking is used as the main track pattern recognition algorithm at CLIC

LCWS presentation about CLIC Conformal Tracking performance

Momentum and Transverse Impact Parameter Resolution

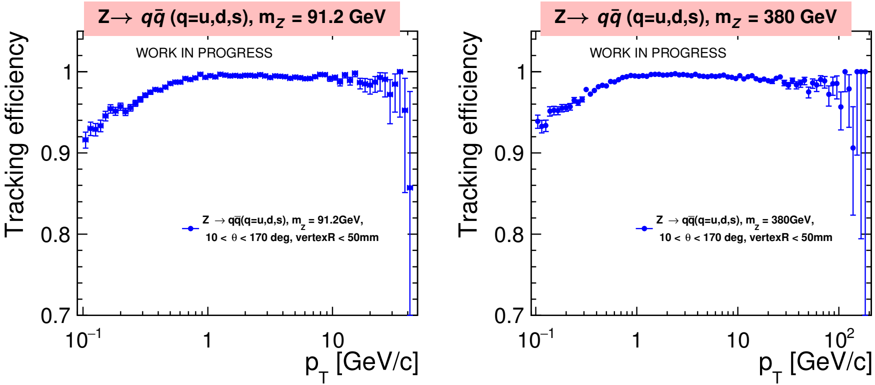




$\sigma_{p_T}/{p_T}^2 \simeq 4{\cdot}10^{-5}$ GeV^{-1}
at p = 100 GeV at 89°

~2 μm at 100 GeV
~6 μm at 10 GeV
~12 μm at 1 GeV

- Detector tracking performance with single muon
- Excellent impact parameter resolution, as required for efficient b- and c-tagging



$$\text{Tracking efficiency} = \frac{N_{tracks}^{reconstructed}}{N_{particles}^{reconstructable}}$$

- reconstructable particles:
  - $N_{hits} \geqslant 4$
  - $|\cos(\theta)| < 0.99$
  - $p_T \geqslant 0.1$ GeV/c
  - particle track is not a loop (does not have two hits on the same layer of the same subdetector)

ECAL

- SiW sampling calorimeter
- Cell size: 5x5 mm^2
- 40 layers, 22 X_0
- Identical to CLIC ECAL $\rightarrow$ to keep good photon energy resolution

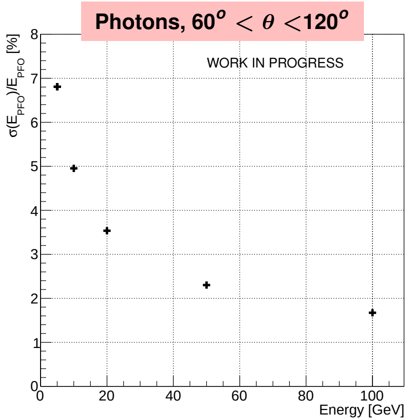
HCAL

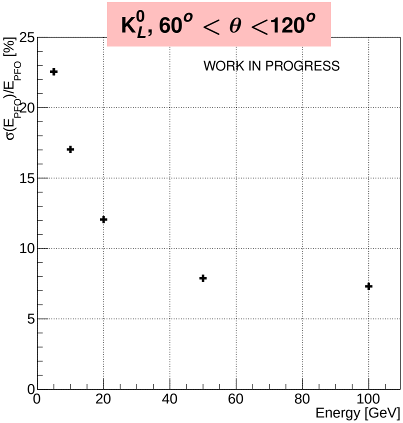
- steel + scintillator sampling calorimeter
- Cell size: 3x3 cm^2
- 44 layers, 5.5 λ_I
- Depth is inspired by HCAL for ILD detector (optimized for 500 GeV)

- High-granularity calorimeters allows one to separate clusters from different particles in jets and to track precisely EM and hadron showers
- Particle-flow reconstruction algorithm: PandoraPFA

- Default calibration procedure by Pandora (the same as used for ILD and CLIC):
  - Energy calibration: 10 GeV photons, 10 GeV muons and 50 GeV K_L^0 single particle gun samples
  - Photon ID Likelihood: hadronically decaying Z events sample at 380 GeV

Neutral Particles Energy Resolution

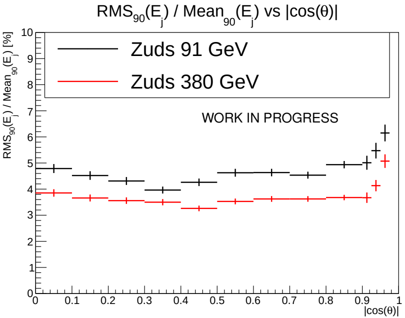


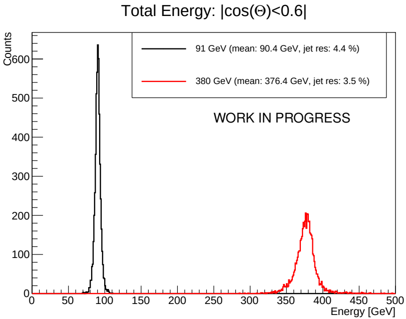


$\sigma_E/E \simeq 1.6$ %
reached for 100 GeV photons

$\sigma_E/E \simeq 7.3$ %
reached for 100 GeV K_L^0

- Good energy resolution for neutral particles
- Energy of charged particles is estimated from tracking





- Total energy is reconstructed with 1% accuracy:
  - 91 GeV: 90.4 GeV
  - 380 GeV: 376.4 GeV
- Jet energy resolution in barrel region:
  - 91 GeV: 4.4 %
  - 380 GeV: 3.5 %
- comparable resolution with the CLIC detector

$$\frac{\mathrm{RMS}_{90}(E_j)}{\mathrm{mean}_{90}(E_j)} = \frac{\mathrm{RMS}_{90}(E_{jj})}{\mathrm{mean}_{90}(E_{jj})}\sqrt{2}$$

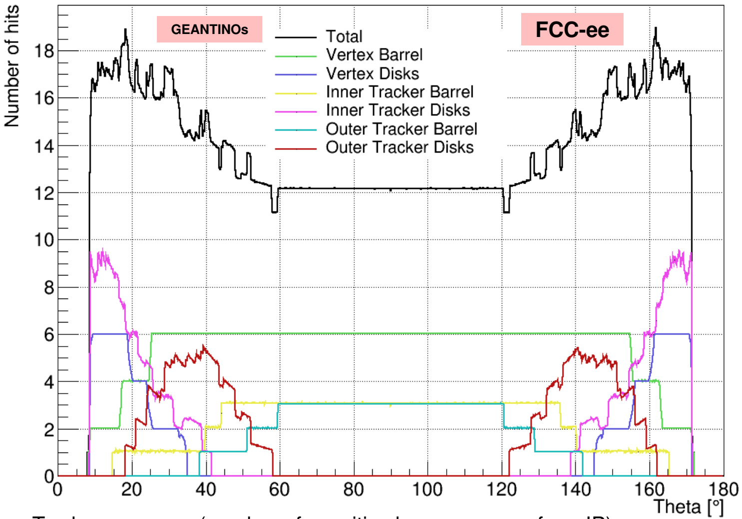
arXiv:1209.4039

Summary

- The design of CLIC-inspired all-silicon detector for FCC-ee has been presented
- Background studies demonstrate that dominant contribution to the detector occupancy originates from $\gamma\gamma \rightarrow e^{+}e^{-}$ which constrains electronics readout time to $\approx$0.4 μs for VTX and Tracker detectors at 91.2 GeV.
  At 365 GeV it is much more relaxed because of the much larger bunch spacing (8533 ns vs. 20 ns)
- Performance studies based on the full simulation demonstrate that proposed detector design for FCC-ee provides comparable tracking and calorimetry performance w.r.t. CLIC detector

Thank you for attention!

BACKUP



- Tracker coverage (number of sensitive layers as seen from IP).
- More than 12 hits over theta range 8.6° - 171.4°

Overall dimensions of CLIC and FCC-ee detectors

	CLIC		FCC-ee
VTX Barrel	31-60 mm	$\Longrightarrow$	17-59 mm
VTX Endcap	Spirals	$\Longrightarrow$	Disks
Tracker radius	1486 mm	$\Longrightarrow$	2100 mm
ECAL thickness	40 layers, 22 X_0	$\Longrightarrow$	40 layers, 22 X_0
HCAL thickness	60 layers, 7.5 λ_I	$\Longrightarrow$	44 layers, 5.5 λ_I
Yoke thickness	1989 mm	$\Longrightarrow$	1521 mm
MDI (forward region)		$\Longrightarrow$	$<$ 150 mrad
Solenoid field	4 Tesla	$\Longrightarrow$	2 Tesla