A CLIC-inspired detector for FCC-ee

FCC Week – 30.5.2017

Emilia Leogrande, on behalf of the CERN Linear Collider Detector group (EP-LCD)
Outlook of this talk

- CLIC DETECTOR LAYOUT AND PERFORMANCE
  - Detector requirements
    - from physics
    - from experimental conditions
  - Detector layout
  - Simulation and reconstruction software tools
  - Detector performances

- THE CLIC-INSPIRED DETECTOR FOR FCC-ee
  - Experimental conditions and interaction region
  - Detector layout
    - Vertex
    - Tracker
    - ECal
    - HCal
    - Yoke and muon ID
  - Next steps
  - The CDR Chapter
CLIC detector layout and performances
CLIC Detector requirements from physics

- momentum resolution
  - Higgs recoil mass, Higgs coupling to muons, BSM (smuon and neutralino masses)
  - for high $p_T$ tracks

\[ \frac{\sigma_{p_T}}{p_T^2} \simeq 2 \times 10^{-5} \text{GeV}^{-1} \]

Example: $H \rightarrow \mu\mu$ @ 3 TeV

Di-muon invariant mass [GeV]
CLIC Detector requirements from physics

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  $$\sigma_{p_T} / p_T^2 \simeq 2 \times 10^{-5} \, GeV^{-1}$$

- **jet energy resolution**
  - W/Z di–jet mass separation
  - jet energy up to 1 TeV
  
  $$\sigma_{E/E} \simeq 3.5\%$$
CLIC Detector requirements from physics

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- **impact parameter resolution**
  - c/b tagging, Higgs BR
    \[ \sigma_{d_0}^2 = a^2 + \frac{b^2}{p^2 \sin^3 \theta} \]
    \[ a \lesssim 5 \mu m \quad b \lesssim 15 \mu m \text{GeV} \]
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- **lepton ID efficiency** > 95% over full energy range
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  ![Example: \( H \to \mu\mu \) @ 3 TeV](image)

- **jet energy resolution**
  - W/Z di-jet mass separation
  - jet energy up to 1 TeV
  \[
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  \]

  ![Graph showing jet energy resolution](image)

- **impact parameter resolution**
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- **lepton ID efficiency** > 95 %
  - over full energy range

- **forward coverage**
  - electron and photon tagging (e.g. dark matter studies)
Detector requirements from experimental conditions

BEAM STRUCTURE

CLIC Beam

$T = 20[\text{ms}]$

$312 \times 500 \text{ps}$

$156 \text{ns}$

$t$
Detector requirements from experimental conditions

**BEAM STRUCTURE**

CLIC Beam

\[ T = 20 \text{[ms]} \]

**BACKGROUND**

Small bunch size => strong beamstrahlung

<table>
<thead>
<tr>
<th>bunch size</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_x )</td>
<td>45 nm</td>
</tr>
<tr>
<td>( \sigma_y )</td>
<td>1 nm</td>
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1. \( e^+e^- \) pairs

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**BEAM STRUCTURE**

CLIC Beam

\[ T = 20 \text{[ms]} \]

312 x 500ps 156ns

**BACKGROUND**

Small bunch size =>
strong beamstrahlung

1. e⁺e⁻ pairs
2. γγ→hadrons

| bunch size |  
|------------|---|
| σₓ         | 45 nm  |
| σᵧ         | 1 nm   |
| σ₂z        | 44 μm  |

γ/γ⁺→q, q̅
Detector requirements from experimental conditions

**BEAM STRUCTURE**

![CLIC Beam diagram]

- $T = 20[ms]$
- $312 \times 500ps$
- $156ns$

**BACKGROUND**

Small bunch size => strong beamstrahlung

1. $e^+e^-$ pairs
2. $\gamma\gamma \rightarrow$ hadrons

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**HITS OCCUPANCY: IMPACT ON THE DETECTOR**

- Segmentation
  - vertex pixels: 25x25 $\mu$m$^2$
  - short strips/pixels in some tracker regions
  - high-granularity calorimeter
- Precise hit timing
  - 10ns hit time stamping in vertex+tracker
  - 1ns accuracy for calorimeter hits
Detector requirements from experimental conditions

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**THE PRO OF LOW DUTY CYCLE**

- Cooling realized by air flow (vertex)/water
  + POWER PULSING
- allows to reduce material budget in the vertex+tracker
- allows to have compact calorimeters

*will not be the case for FCC-ee!
CLIC Detector layout

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CLIC Detector layout

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Simulation and reconstruction software tools

- DD4Hep is the single source of geometry information for simulation, reconstruction and analysis
  - DetElements [C++ drivers which interpret XML files with detector parameters]
    - => for simulation
  - DDRec DataStructures [reconstruction interfaces filled by C++ drivers]
  - DD4Hep Surfaces [position of hits, local–to–global coordinate transformation, average material]
    - => for reconstruction

DD4Hep is the single source of geometry information for simulation, reconstruction and analysis.

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Geometry interface to the track reconstruction

[Link to presentation](https://indico.cern.ch/event/505613/contributions/2230854/attachments/1347096/2046776/Oral-472_sailer_RecoWDD4hep.pdf)
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Geometry interface to the track reconstruction

- Pattern recognition/track finding algorithms
- Track fitting (DDKalTest, aidaTT)

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Geometry interface to the track reconstruction

- Pattern recognition/track finding algorithms
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**DDMarlinPandora** glues DD4Hep, the Linear Collider Framework (Marlin), and PandoraPFA

- DDRec DataStructures
- tracks
- calorimeter hits

- PandoraPFA [pattern recognition algorithm in high–granularity calorimeters]

Detector performance examples

Momentum resolution

\[ \frac{\sigma_{p_T}}{p_T^2} \approx 2 \times 10^{-5} \text{GeV}^{-1} \]

reached for high energy muons in the central region

\[ \sigma_{\Delta p_T/p_T^{\text{true}}} \]

\[ \approx \begin{cases} 10^{-1} & \text{for } 0 = 10 \text{ deg} \\ 10^{-2} & \text{for } 0 = 30 \text{ deg} \\ 10^{-3} & \text{for } 0 = 89 \text{ deg} \end{cases} \]
Detector performance examples

Momentum resolution

\[ \frac{\sigma_{p_T}}{p_T^2} \approx 2 \times 10^{-5} \text{GeV}^{-1} \]

reached for high energy muons in the central region

\[ \sigma_{\Delta p_T/p_{T,\text{true}}} \]

Photon energy resolution

\[ \sigma_{E/E_{\text{true}}} \approx 1.5\% \]

reached for 100 GeV photons with the current detector model (CLICdet_40)
Experimental conditions and layout for the FCC-ee CLIC-like detector

- Requirements from physics
  
  See talk by M. Dams

- Requirements from experimental conditions
  
  —> following slides
Experimental conditions

- Large number of bunches —> crossing angle 30mrad to avoid parasitic collisions

- Last focusing quadrupole close to IP (L*=2.2m)
- Compensating solenoid to prevent emittance blow-up due to non-zero crossing angle

=> limit to experiment B field = 2 T

<table>
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<tr>
<th>energy/beam [GeV]</th>
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<td>Bunch spacing [ns]</td>
<td>3.0</td>
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A CLIC-inspired detector for FCC-ee – FCCWeek 30.5.2017 | Emilia Leogrande
Experimental conditions – Interaction region

- Large number of bunches $\rightarrow$ crossing angle 30mrad to avoid parasitic collisions
- Last focusing quadrupole close to IP ($L^*=2.2m$)
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  - $\Rightarrow$ limit to experiment B field = 2 T

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- Beam–beam background per BX
  - e+e- pairs
  - γγ→hadrons
  - Synchrotron radiation

See talk by G. Voutsinas
Detector layout/ Vertex
INNER LAYER closer to the beam pipe
depends on beam-induced background

BARREL LENGTH = 250 mm
Detector layout/ Vertex

- INNER LAYER closer to the beam pipe
- depends on beam-induced background

BARREL LENGTH = 250 mm

Scale all the barrel layers*

<table>
<thead>
<tr>
<th>double layer radius [mm]</th>
<th>CLIC</th>
<th>FCC</th>
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<tbody>
<tr>
<td>1st</td>
<td>31-33</td>
<td>17-19</td>
</tr>
<tr>
<td>2nd</td>
<td>44-46</td>
<td>37-39</td>
</tr>
<tr>
<td>3rd</td>
<td>58-60</td>
<td>57-59</td>
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*layer thickness may need to be increased to accommodate water cooling
Detector layout / Vertex

- INNER LAYER closer to the beam pipe
- depends on beam-induced background

BARREL LENGTH = 250 mm

Disks to replace spirals (no need for air flow)

<table>
<thead>
<tr>
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<th>double disk z [mm]</th>
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<tbody>
<tr>
<td>1st</td>
<td>159–161</td>
</tr>
<tr>
<td>2nd</td>
<td>229–231</td>
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<td>3rd</td>
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- DISKS INNER RADIUS closer to the beam pipe
Support tube

Detector layout/ Tracker
OUTER BARREL RADIUS to be increased to 2.14 m to compensate for the lower B
OUTER BARREL RADIUS to be increased to 2.14 m

to compensate for the lower B

Support tube*

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<td>inner</td>
<td>575</td>
<td>675</td>
</tr>
<tr>
<td>outer</td>
<td>600</td>
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*to be checked for mechanical stability
OUTER BARREL RADIUS to be increased to 2.14 m
to compensate for the lower B

Support tube*

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**Detector layout/ Tracker**

- OUTER BARREL RADIUS to be increased to 2.14 m
- to compensate for the lower B

**Scale all the barrel layers**

<table>
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<tbody>
<tr>
<td>ITB1</td>
<td>127</td>
<td>127</td>
</tr>
<tr>
<td>ITB2</td>
<td>340</td>
<td>400</td>
</tr>
<tr>
<td>ITB3</td>
<td>554</td>
<td>670</td>
</tr>
<tr>
<td>OTB1</td>
<td>819</td>
<td>1000</td>
</tr>
<tr>
<td>OTB2</td>
<td>1153</td>
<td>1568</td>
</tr>
<tr>
<td>OTB3</td>
<td>1486</td>
<td>2136</td>
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*layer thickness may need to be increased to accommodate more water cooling

**Support tube**

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### Detector layout/Tracker

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#### Scale all the disks sizes

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<td><strong>ITD1</strong></td>
<td>72</td>
<td>78</td>
</tr>
<tr>
<td><strong>ITD2</strong></td>
<td>99</td>
<td>121</td>
</tr>
<tr>
<td><strong>ITD3</strong></td>
<td>131</td>
<td>163</td>
</tr>
<tr>
<td><strong>ITD4</strong></td>
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<td>206</td>
</tr>
<tr>
<td><strong>ITD5</strong></td>
<td>197</td>
<td>249</td>
</tr>
<tr>
<td><strong>ITD6</strong></td>
<td>231</td>
<td>291</td>
</tr>
<tr>
<td><strong>ITD7</strong></td>
<td>250</td>
<td>328</td>
</tr>
<tr>
<td><strong>OTD1–4</strong></td>
<td>618</td>
<td>718</td>
</tr>
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#### Disk inner radius [mm]

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<td>404</td>
<td>460</td>
</tr>
<tr>
<td><strong>ITD2</strong></td>
<td>551</td>
<td>652</td>
</tr>
<tr>
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<td>554</td>
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<td>552</td>
<td>652</td>
</tr>
<tr>
<td><strong>OTD1–4</strong></td>
<td>1430</td>
<td>2080</td>
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Detector layout/ Tracker

Inner tracker disks — min radius down to 150 mrad

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Detector layout/ ECal
ECal BARREL INNER RADIUS changed to 2.15 m
due to larger tracker

ECal ENDCAP
- z position unchanged
- transverse size adjusted
  - inner radius = 250 mm -> available space?
  - outer radius = 2.35 m
Detector layout/ ECal

- ECal BARREL INNER RADIUS changed to 2.15 m
  - due to larger tracker

- ECal ENDCAP
  - z position unchanged
  - transverse size adjusted
    - inner radius = 250 mm → available space?
    - outer radius = 2.35 m

- STRUCTURE unchanged:
  - SiW sampling calorimeter
  - Cell size: 5x5 mm²
  - Number of radiation lengths: 22 X0
  - Number of layers: 40

- DISTANCE BETWEEN LAYERS: might have to be revised due to need for cooling ⇒ sampling fraction will be worse
Detector layout/ ECal

- **ECal BARREL INNER RADIUS** changed to 2.15m
  - due to larger tracker

- **ECal ENDCAP**
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- **STRUCTURE unchanged:**
  - SiW sampling calorimeter
  - Cell size: 5x5 mm²
  - Number of radiation lengths: 22 X0
  - Number of layers: 40

- **DISTANCE BETWEEN LAYERS**: might have to be revised due to need for cooling => sampling fraction will be worse
- STRUCTURE unchanged:
  - steel + scintillator sampling calorimeter
HCal BARREL INNER RADIUS changed to 2.4m due to larger tracker

HCal ENDCAP size adjusted
- outer radius = 3.57 m
- outer z = 3.71 m (CLIC: 4.13 m)

STRUCTURE unchanged:
- steel + scintillator sampling calorimeter
Detector layout/ HCal

- HCal BARREL INNER RADIUS changed to 2.4m
  - due to larger tracker

- HCal ENDCAP
  - size adjusted
    - outer radius = 3.57 m
    - outer z = 3.71 m (CLIC: 4.13 m)

- STRUCTURE unchanged:
  - steel + scintillator sampling calorimeter

- Segmentation adjusted:
  - Number of layers: 44
  - Number of interaction lengths: $5.5 \, \lambda_0$
    - CLIC: 7.5 $\lambda_0$
    - ILD: 5.5 $\lambda_0$ (optimized for 500GeV
      => similar energy scale as FCC)
Yoke shields stray field, especially along the beam
+ improves muon ID
Yoke shields stray field, especially along the beam
+ improves muon ID

🌟 STRUCTURE unchanged:
🌟 Fe yoke equipped with muon chambers
🌟 RPCs 30x30 mm²
🌟 7 layers equally spaced
Detector layout/ Yoke and Muon ID System

- Yoke shields stray field, especially along the beam + improves muon ID

- STRUCTURE unchanged:
  - Fe yoke equipped with muon chambers
  - RPCs 30x30 mm²
  - 7 layers equally spaced

- Size and position adjusted
  - scaled out due to larger tracker
  - thinner for smaller B

YOKE BARREL

<table>
<thead>
<tr>
<th>radius [m]</th>
<th>CLIC</th>
<th>FCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>inner</td>
<td>4.46</td>
<td>4.48</td>
</tr>
<tr>
<td>outer</td>
<td>6.45</td>
<td>6.00</td>
</tr>
</tbody>
</table>

YOKE ENDCAPS

<table>
<thead>
<tr>
<th>radius [m]</th>
<th>CLIC</th>
<th>FCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>inner</td>
<td>0.49</td>
<td>0.40</td>
</tr>
<tr>
<td>outer</td>
<td>6.45</td>
<td>6.00</td>
</tr>
</tbody>
</table>
Next steps

- Impact of background hits to be investigated
- Thickness of vertex/tracker layers
  - examine the coverage (Nhits vs polar angle)
  - studies ongoing to determine the effect of increasing the material budget to accommodate the needed additional cooling
  - feasibility of cooling and support structures
- Position of vertex/tracker layers
  - performance studies (momentum resolution, tracking efficiency) ongoing
- Longitudinal segmentation of calorimeters
  - may need to be revised to accommodate the needed additional cooling
- Dimensions of yoke and muon identification system
A CLIC-inspired detector for FCC-ee

1. Overview
2. Vertex Detectors
3. Tracking System
4. Calorimetry
   4.1 Electromagnetic Calorimeter
   4.2 Hadronic Calorimeter
5. Yoke and Muon Identification System
6. Physics Performance
   6.1 Simulation and Reconstruction
   6.2 Performance for Lower Level Physics Observables
      6.2.1 Muon and Electron Energy Resolution
      6.2.2 Jet Reconstruction
      6.2.3 Particle Identification Performance
      6.2.4 Flavour Tagging
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Thank you for your attention
A CLIC-inspired detector for FCC-ee – FCCWeek 30.5.2017 | Emilia Leogrande
CLIC/ Beam conditions

Staging scenario: 11km, 29km, 50km

Integrated luminosity [fb⁻¹]

- 380 GeV
- 1.5 TeV
- 3 TeV

Year

Two-beam acceleration scheme at 12 GHz, gradient of 100MV/m
## Detector layout/ Vertex and Tracker sensitive areas

<table>
<thead>
<tr>
<th>subdetector</th>
<th>CLIC sensor area [m²]</th>
<th>FCC sensor area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTX barrel</td>
<td>0.487</td>
<td>0.358</td>
</tr>
<tr>
<td>VTX endcaps</td>
<td>0.351 (spirals)</td>
<td>0.185 (disks)</td>
</tr>
<tr>
<td>ITD1</td>
<td>0.63</td>
<td>0.56</td>
</tr>
<tr>
<td>ITD2</td>
<td>1.13</td>
<td>1.29</td>
</tr>
<tr>
<td>ITD3</td>
<td>1.10</td>
<td>1.25</td>
</tr>
<tr>
<td>ITD4</td>
<td>1.03</td>
<td>1.20</td>
</tr>
<tr>
<td>ITD5</td>
<td>0.98</td>
<td>1.14</td>
</tr>
<tr>
<td>ITD6</td>
<td>0.94</td>
<td>1.07</td>
</tr>
<tr>
<td>ITD7</td>
<td>0.91</td>
<td>1.00</td>
</tr>
<tr>
<td>OTD1–4</td>
<td>6.96</td>
<td>11.98</td>
</tr>
<tr>
<td>ITB1</td>
<td>0.79</td>
<td>0.77</td>
</tr>
<tr>
<td>ITB2</td>
<td>2.20</td>
<td>2.42</td>
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<tr>
<td>ITB3</td>
<td>5.22</td>
<td>5.83</td>
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<tr>
<td>OTB1</td>
<td>14.30</td>
<td>15.88</td>
</tr>
<tr>
<td>OTB2</td>
<td>20.32</td>
<td>24.91</td>
</tr>
<tr>
<td>OTB3</td>
<td>26.04</td>
<td>33.93</td>
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Detector layout/ Solenoid and Magnetic Yoke
Detector layout/ Solenoid and Magnetic Yoke

Coil
- scaled out due to larger tracker
- thinner for smaller B field

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<td>3649</td>
<td>3885</td>
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<tr>
<td>outer</td>
<td>3993</td>
<td>3975</td>
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Vacuum tank

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- STRUCTURE unchanged:
  - Fe yoke equipped with muon chambers
  - RPCs 30x30 mm²
Detector layout/ Solenoid and Magnetic Yoke

Solenoid

- radius [mm]
  - CLIC: 3649
  - FCC: 3885
  - CLIC: 3993
  - FCC: 3975

Vacuum tank

- radius [mm]
  - CLIC: 3483
  - FCC: 3719
  - CLIC: 4290
  - FCC: 4272

Yoke

- Yoke shields stray field, especially along the beam
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STRUCTURE unchanged:

- Fe yoke equipped with muon chambers
- RPCs 30x30 mm²

Size and position adjusted

- scaled out due to larger tracker
- thinner for smaller B field

ENDCAPS

- radius [mm]
  - CLIC: 4461
  - FCC: 4479
  - CLIC: 490
  - FCC: 400
  - CLIC: 6450
  - FCC: 6000

BARREL

- z [mm]
  - CLIC: 4179
  - FCC: 3576
  - CLIC: 5700
  - FCC: 5100