PFA Oriented ECAL Simulation and Geometry Optimization for the CEPC

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On behalf of CEPC Software and Calorimeter Working Group

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Outline

• Tools:
  – Simulation: Software setup & Geometries
  – Reconstruction: ArborPFA

• Optimization of ECAL Geometry
  – Cell Size & Photon Shower Separation
  – Longitudinal Structures & EM Energy Measurements
    • Absorber thickness
    • Number of ECAL layers

• Summary and Plan
CEPC Full Simulation Software

- **Generator**: Whizard, PYTHIA
  - req: Geant4, Database...
- **Simulation**: Mokka
  - Digitization: MarlinReco, etc.
    - eg: G2CD Digitized Detector Hits
- **MarlinReco**, etc.
  - Tracks.
- **Stdhep**
  - GDML/Root
- **Evt Display**: Druid
- **PFA**
  - Pandora/Arbor Cluster, Recon-Particles
- **Flavor Tagging**: LCFIPlus
- **Analysis**: Marlin, Root

**Physics Result**

**Simulation Calibration Reconstruction Analysis Chain**
## CEPC Detector Model

<table>
<thead>
<tr>
<th>Sub-detector</th>
<th>CEPC_v1</th>
<th>CEPC_v4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube &amp; Mask</td>
<td>Single pipe</td>
<td>New MDI design—doubly pipe</td>
</tr>
<tr>
<td>Lcal</td>
<td>$R: \ 60 \text{ mm to } 172 \text{ mm}$</td>
<td>$R: \ 30 \text{ mm to } 100 \text{ mm}$</td>
</tr>
<tr>
<td>VXD</td>
<td>$16\text{mm/62.5mm, 37mm/125mm, 58/125mm}$</td>
<td>Same as CEPC_v1</td>
</tr>
<tr>
<td></td>
<td>$\text{220mm, 371.3mm, 645mm, 846mm, }$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\text{1057.5mm}$</td>
<td></td>
</tr>
<tr>
<td>FTD</td>
<td>$153\text{mm, 300mm, 1811mm, 1813.5mm}$</td>
<td>Same as CEPC_v1</td>
</tr>
<tr>
<td>SIT &amp; SET</td>
<td>Sensitive Radius: $384\text{mm to } 1718\text{mm}$</td>
<td>Same as CEPC_v1</td>
</tr>
<tr>
<td>TPC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecal</td>
<td>$R: \ 1843\text{mm to } 2028\text{mm};$</td>
<td>Cell size: $10.1657\text{mm}$ $\text{Rin}_{\text{endcap}}: \ 245 \text{ mm}$</td>
</tr>
<tr>
<td></td>
<td>$Z: \ 2450\text{mm to } 2635\text{mm};$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cell size: $5.0833\text{mm}$ $\text{Rin}_{\text{endcap}}: \ 226.8 \text{ mm}$</td>
<td></td>
</tr>
<tr>
<td>Hcal</td>
<td>$R: \ 2058\text{mm to } 3385.53\text{mm};$</td>
<td>$R: \ 2058\text{mm to } 3143.43\text{mm};$</td>
</tr>
<tr>
<td></td>
<td>Cell size: $10.408 \text{ mm;}$ 48 layers</td>
<td>$Z: \ 2650\text{mm to } 3735.43\text{mm};$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\text{40 layers}$</td>
</tr>
<tr>
<td>Yoke</td>
<td>$\text{Rin = 4415(barrel), 300(endcap)}$</td>
<td>$\text{Rin = 4174(barrel), 300(endcap) (240 for MDI)}$</td>
</tr>
<tr>
<td>Field</td>
<td>$3.5 \text{ T}$</td>
<td>$3.0 \text{ T}$</td>
</tr>
</tbody>
</table>

Smaller BField ($3.5 \to 3\text{T}$), Thinner HCAL ($48 \to 40\text{Layers}$), MDI/Yoke System, etc.
CEPC Simplified Geometry

• **Goal:**
  to understand the ultimate clustering performance & set reference for geometry defect impacts study.
  
  • calorimeter only
  • ideal geometry (Cylindrical barrel layer).
  • totally homogeneous, with no geometry defects
  • easily modified
PFA @ ECAL

• Energy measurement, especially for photons

• Separation
Photon Energy Measurement by ArborPFA

Photon shower energy collection efficiency

Photon energy resolution before and after reconstruction

Efficiency = LC Energy/total hit energy
Nearby EM-Shower Separation

Lots of nearby EM-showers exist in jets, the separation and reconstruction of them are important for some physics objects.

The reconstruction efficiency of two parallel 5GeV photons was studied. The distance between these two photons ranges from 1mm to 80mm.

\[ \frac{1}{3} E_{\text{All}} < E_{\text{photon1}} < \frac{2}{3} E_{\text{All}} \quad \& \quad \frac{1}{3} E_{\text{All}} < E_{\text{photon2}} < \frac{2}{3} E_{\text{All}} : \text{succeeded} \]
Nearby EM-Shower Separation

Efficiency with different cell size was checked.
At large distance, the reconstruction efficiency converges to 1.
At very close by distance, the reconstruction efficiency drops significantly.

The crucial separation distance is defined as the distance with which the successful reconstruction efficiency is 50%.
ECAL geometry optimization

• Transverse:
  – Cell Size
  photon separation, with physics benchmark of Br(tau->X)

• Longitudinal
  – Total Absorber Thickness
  – Number of Layers & Sensor Thickness
  photon energy resolution
Nearby Photon Showers in Physics Objects

**Z->tau tau**
(at Zpole Energy)

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**Table 2.** Percentage of photons that would be polluted by neighbor particle

<table>
<thead>
<tr>
<th>Cell Size</th>
<th>Crucial Separation Distance with Arbor</th>
<th>Percentage of H→γγ</th>
<th>Percentage of Z→ττ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>≥30GeV</td>
<td>≤30GeV</td>
</tr>
<tr>
<td>1mm</td>
<td>4mm</td>
<td>0%</td>
<td>0.06%</td>
</tr>
<tr>
<td>5mm</td>
<td>9mm</td>
<td>0.007%</td>
<td>0.352%</td>
</tr>
<tr>
<td>10mm</td>
<td>16mm</td>
<td>0.097%</td>
<td>1.12%</td>
</tr>
<tr>
<td>20mm</td>
<td>37mm</td>
<td>0.404%</td>
<td>6.41%</td>
</tr>
</tbody>
</table>

At least ~10mm×10mm effective cell size
Study on ECAL Absorber Thickness

80-90mm Total Tungsten Thickness is reasonable

175GeV photon shower energy deposit in each 1mmW (0.35X₀)

<table>
<thead>
<tr>
<th></th>
<th>95mm W</th>
<th>90mm W</th>
<th>85mm W</th>
<th>80mm W</th>
</tr>
</thead>
<tbody>
<tr>
<td>175GeV</td>
<td>99.0%</td>
<td>98.6%</td>
<td>97.9%</td>
<td>96.9%</td>
</tr>
<tr>
<td>120GeV</td>
<td>99.2%</td>
<td>98.8%</td>
<td>98.2%</td>
<td>97.3%</td>
</tr>
<tr>
<td>45GeV</td>
<td>99.4%</td>
<td>99.1%</td>
<td>98.7%</td>
<td>98.1%</td>
</tr>
</tbody>
</table>
vvHiggs->diphoton Reconstruction

the reconstruction accuracy is mainly decided by the photon energy resolution because the spatial resolution is negligible.

30 layers ECAL with 2.8mmW+0.5mmSi in each layer

resolution(σ/mean) with different total tungsten thickness
Photon energy resolution at different ECAL layer number, and Silicon sensor thickness

0.5mm thick silicon in each layer

less layer gets worth photon energy resolution, due to the less sensor/absorber ratio

thicker sensor can compensate photon energy resolution

30 layers 0.5mm silicon
25 layers 1mm silicon
20 layers 1.5mm silicon
CEPC Detector Model Results

vvHiggs->gluon gluon

**0.5mmSi, 30Layers**

- CEPC Preliminary
- $\chi^2 / \text{ndf}$: 166.4 / 79
- Constant: 286.9 $\pm$ 4.6
- Mean: 125 $\pm$ 0.1
- Sigma: 4.931 $\pm$ 0.050
- Events: 3.94%

**1mmSi, 30Layers**

- CEPC Preliminary
- $\chi^2 / \text{ndf}$: 173.1 / 80
- Constant: 304.9 $\pm$ 4.7
- Mean: 125 $\pm$ 0.1
- Sigma: 4.834 $\pm$ 0.048
- Events: 3.87%

**1mmSi, 20Layers**

- CEPC Preliminary
- $\chi^2 / \text{ndf}$: 210.3 / 80
- Constant: 266.5 $\pm$ 4.5
- Mean: 124.6 $\pm$ 0.1
- Sigma: 5.062 $\pm$ 0.054
- Events: 4.06%

**1.5mmSi, 20Layers**

- CEPC Preliminary
- $\chi^2 / \text{ndf}$: 206.6 / 83
- Constant: 288.7 $\pm$ 4.4
- Mean: 125.2 $\pm$ 0.1
- Sigma: 5.071 $\pm$ 0.051
- Events: 4.04%
Summary

• Dedicated Software tools has been established, for detailed optimization studies

• Recommended ECAL Geometry for CEPC
  • ~10mm*10mm or smaller cell size is needed for EM shower separation in tau jets.
  • Total Tungsten thickness should be 80-90mm.
  • <30 layers is feasible, if thicker sensor can be used to compensate photon energy resolution loss.
Next

- Reconstruction optimization at different geometries

- Development & Validation of Digitization algorithms, Proper modelling of detector response

- Clarify the physics requirements to the sub-detectors & recommed optimize designes to the sub-detector studies
Back Up
Photon Reconstruction by ArborPFA
Nearby Photon Showers in Physics Objects

qq H->γγ
Photon Spatial Resolution

Position Resolution

Angular Resolution

- Cell Size = 20mm*20mm
- Cell Size = 10mm*10mm
- Cell Size = 5mm*5mm
- Cell Size = 1mm*1mm
ECAL R-Z

$qq \to \gamma \gamma$

$Z \to \tau \tau$

TPC Radius [mm]

Per centage of Polute [%]

TPC Radius [mm]
Phton energy resolution with different absorber thickness

45GeV

$\chi^2 / \text{ndf}$: 16.34 / 15
$p_0$: 31.46 ± 0.03722
$p_1$: -1.134 ± 0.000587
$p_2$: 0.01643 ± 5.988e-06
$p_3$: -0.001047 ± 5.548e-08
$p_4$: 2.503e-07 ± 3.831e-10

120GeV

$\chi^2 / \text{ndf}$: 13.94 / 15
$p_0$: 44.87 ± 0.02572
$p_1$: -1.64 ± 0.000384
$p_2$: 0.02327 ± 3.836e-06
$p_3$: -0.0001465 ± 3.46e-08
$p_4$: 3.468e-07 ± 2.404e-10

175GeV

$\chi^2 / \text{ndf}$: 18.72 / 15
$p_0$: 42.96 ± 0.02222
$p_1$: -1.527 ± 0.000324
$p_2$: 0.02099 ± 3.224e-06
$p_3$: -0.0001282 ± 2.884e-08
$p_4$: 2.945e-07 ± 2.015e-10