Electromagnetic calorimeter using LAr technology for FCC-hh

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Outline

Calorimeter system in FCC-hh

- Requirements
- Technologies under consideration

Electromagnetic calorimeter proposal

- Geometry
- Performance of single electrons

Calorimetry in FCC software

Conclusions
Calorimeters in FCC-hh detector

Electromagnetic barrel (ECAL B) + endcap (ECAL EC) + forward (EFCAL)

Hadronic endcap (HCAL EC) + forward (HFCAL)

Hadronic barrel (HCAL B) + extended barrel (HCAL EB)

Coverage of the calorimeter system up to $|\eta| = 6.0$
Requirements for calorimeters at FCC-hh

Electrons / photons, jets, taus, $E_T^{\text{miss}}$ measurements

Requirements

- Good energy and angular resolutions
- Pile-up rejection ($\langle \mu \rangle$ up to $\sim 1000$)
- Radiation hardness
  (5 x $10^{18} \text{n}_{\text{eq}}/\text{cm}^2$, dose up to 5 GGy for 30 ab$^{-1}$ in forward cal.)

Strong requirements on radiation hardness

Use of Particle Flow techniques $\rightarrow$ fine granularity

Timing detectors, radiation hard materials
Benchmark channels (ECAL)

Precision Standard Model measurements

Beyond Standard Model

- Heavy resonances ($Z'\rightarrow ee, W'\rightarrow e\nu, X\rightarrow \gamma\gamma, X\rightarrow jj$)

Requirements

- High energy resolution
- High angular resolution for $p_T$ measurements
- Good linearity of calorimeter response

Calibration & stability is crucial in such harsh environment
Technologies under consideration

Reference geometry
(inspired by ATLAS calorimetry with excellent conventional calorimetry and in addition high granularity to optimise for Particle Flow techniques)

- LAr / Pb (Cu) *(this talk)*
  - ECAL + hadronic endcap / forward
- Scintillating tiles / Fe with SiPM *(C. Neubüser)*
  - HCAL barrel + extended barrel

Other options considered for ECAL

- Digital Si / W *(T. Price)*
- Analog Si / W *(not yet studied)*

HCAL granularity studies using scintillator / Fe *(S. Chekanov)*

<table>
<thead>
<tr>
<th></th>
<th>Max. eq. fluence [n/cm²]</th>
<th>Max. dose [MGy]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECAL B</td>
<td>$4 \times 10^{15}$</td>
<td>~0.1</td>
</tr>
<tr>
<td>ECAL EC</td>
<td>$3 \times 10^{16}$</td>
<td>~1</td>
</tr>
<tr>
<td>HCAL EC</td>
<td>$2 \times 10^{16}$</td>
<td>~1</td>
</tr>
<tr>
<td>HCAL B</td>
<td>$4 \times 10^{14}$</td>
<td>$6 \times 10^{-3}$</td>
</tr>
<tr>
<td>HCAL EB</td>
<td>$4 \times 10^{14}$</td>
<td>$6 \times 10^{-3}$</td>
</tr>
<tr>
<td>1st layer IB</td>
<td>$6 \times 10^{17}$</td>
<td>$4 \times 10^{2}$</td>
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</tbody>
</table>
Reference geometry for calorimeters

High-granularity calorimeter using LAr / Pb (Cu) + scintillators / Steel technologies

2-4 x better granularity than ATLAS calorimeters

- Granularity to be optimized based on further studies (e.g. pile-up rejection)

<table>
<thead>
<tr>
<th>NAME</th>
<th>Technology</th>
<th>$\eta$ coverage</th>
<th># long.layers</th>
<th>$\Delta \eta \times \Delta \varphi$</th>
<th># channels ($\times 10^5$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECAL B</td>
<td>LAr / Pb</td>
<td>&lt; 1.7</td>
<td>8</td>
<td>0.01 x 0.012</td>
<td>1.3</td>
</tr>
<tr>
<td>ECAL EB</td>
<td>LAr / Pb</td>
<td>1.5 – 2.5</td>
<td>6</td>
<td>0.01 x 0.012</td>
<td>0.6</td>
</tr>
<tr>
<td>HEC</td>
<td>LAr / Cu</td>
<td>1.7 – 2.5</td>
<td>6</td>
<td>0.025 x 0.025</td>
<td>0.1</td>
</tr>
<tr>
<td>EFCal</td>
<td>LAr / Pb</td>
<td>2.3 – 6.0</td>
<td>6</td>
<td>0.025 x 0.025</td>
<td>0.5</td>
</tr>
<tr>
<td>HFCal</td>
<td>LAr / Cu</td>
<td>2.3 – 6.0</td>
<td>6</td>
<td>0.05 x 0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>HCAL B</td>
<td>Scint. Tiles / Stain. Steel</td>
<td>&lt; 1.3</td>
<td>10</td>
<td>0.025 x 0.025</td>
<td>0.2</td>
</tr>
<tr>
<td>HCAL EB</td>
<td>Scint. Tiles / Stain. Steel</td>
<td>1.0 – 1.8</td>
<td>8</td>
<td>0.025 x 0.025</td>
<td>0.07</td>
</tr>
<tr>
<td>Total</td>
<td>LAr / Pb</td>
<td>1.0 – 1.8</td>
<td></td>
<td></td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>LAr / Cu</td>
<td></td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Scint. Tiles / Stain. Steel</td>
<td></td>
<td></td>
<td></td>
<td>0.3</td>
</tr>
</tbody>
</table>
ECAL barrel geometry

Detector with larger longitudinal and transversal granularity compared to ATLAS

- Possible only with straight multilayer electrodes

Proposal: **Inclined plates of absorber (Pb) + active material (LAr) + multilayer readout (PCB)**

- Pros: Easy construction
- Cons: Sampling fraction changes with radius
  - Goal energy resolution of $10\% / \sqrt{E} \oplus 1\%$
ECAL barrel + endcap

Barrel

- Absorber plates (2mm) inclined by angle of $30^\circ$
- LAr thickness increasing with radius 3 - 5.4 mm (LAr / Pb ratio: 1.5 - 2.7)
- $29 \, X_0$ at $\eta = 0$ (1.5 $X_0$ in front of the active detector)

Endcaps

- Parallel discs of absorber

Cryostat material has to be optimized ($\eta > 1$)
EM scale calibration

Sampling fraction changes with radius

- EM scale calibration done per layer

100 GeV electrons, $\eta = 0, 1.5 \ X_0$

Good energy resolution with 8 longitudinal layers
Performance of single electrons

Simulations of single electrons

- Without pile-up and electronic noise

Correction for energy loss in cryostat calculated from the energy deposit in the 1st longitudinal layer

Goal energy resolution achieved

Good linearity
Pile-up

High pile-up ($\langle \mu \rangle = 1000$) at FCC-hh

- Important to study the reconstruction under these conditions

Total noise: electronics $\oplus$ pile-up

Estimate of pile-up noise in calorimeter

- Longitudinal layers of the same size (~8 cm)
- Very high pile-up contribution in the 1$^{\text{st}}$ layer
  - Thinner layer less sensitive to pile-up
- Geometry optimization needed
Calorimeters in FCC software

Reference geometry

- ECAL barrel (done)
- Hadronic barrel + extended barrel (done)
- ECAL + hadronic endcaps (done)
- ECAL + hadronic forward (to be done)

Reconstruction

- Electron / gamma reconstruction with the clustering algorithm (done)
- Topological clusters (work in progress)
- Particle flow (to be done)
Conclusions

All tools in place for a detailed design optimization studies up to $|\eta| = 6$

Goal energy resolution achieved in ideal conditions

- To be optimized for high pile-up environment

Si / W option for ECAL to be studied
Upstream energy correction

FCC-hh simulation

$100 \text{ GeV } e^-, B = 4T$

Energy of the particle (GeV)

Parameter $P_0$

Parameter $P_1$
Geometry optimization studies

- Pointing geometry
- Upstream energy correction
- Pile-up noise reduction
- Neutral pions identification

Current geometry

Proposal for optimisation