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Description of the AHCAL Detector in Mokka

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Abstract

This is a technical note describing the AHCAL implementation for the ILD concept in the Mokka. It consists of the geometry for the Barrel, Endcaps and EndcapRings. It valids starting with model ILD_o1_v05. The purpose is to help people who involved in the Mokka simulation for the DBD to have an overview of the AHCAL description.

Contents

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1 Introduction of the AHCAL

One previous of the AHCAL [1] description has been documented in [LC-TOOL-2008-001] [2].

The AHCAL detector consists of the following parts: Barrel, Endcaps (for full solid angle coverage) and EndcapRings (to fill the gap between the Barrel and the Endcaps), as shown in Figures 1. Which has been updated with the current engineering design for the DBD studies.

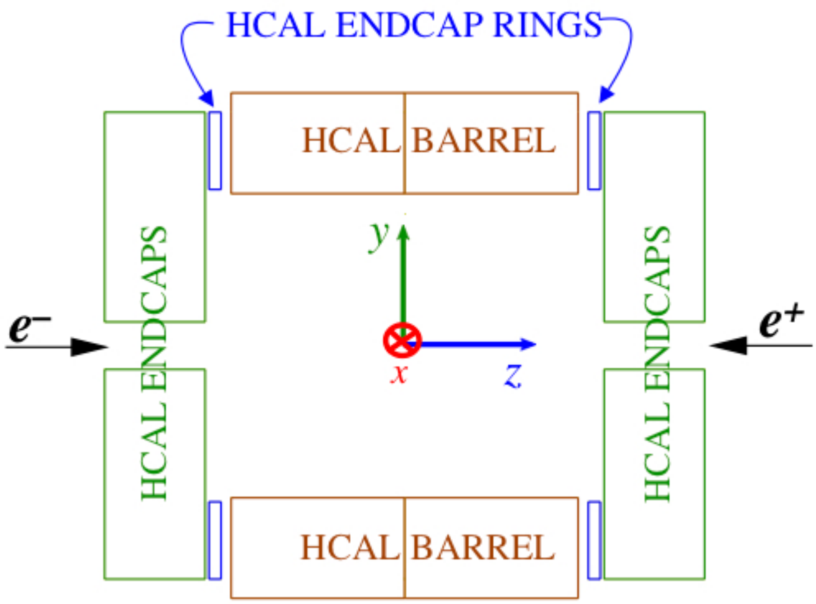

Figure 1: The Barrel, Endcaps and EndcapRings are still needed. But the Endcaps has been redesigned by the engineer to fit the realistic technical design requirement, which will be described in the following chapters.

The up-to-date Mokka [3] drivers validated with model ILD_o1_v05, which will be described in this note in details.

2 The update of the AHCAL

The details of the geometrical description of the new version AHCAL detector will be documented here with the up-to-date numbers. The geometry of the AHCAL detector has been defined with a set of parameters, which saved in the Mokka database as a model.

The numbers shown in this note came from Mokka model ILD_o1_v05. The AHCAL related parameters in Mokka model ILD_o1_v05 can be seen in table 1. Note that the default values of the parameters can be changed by the user at run time too.

No.	Parameter Name	Meaning	Default
1	*Ecal_endcap_zmin*	starting z for ECAL endcap, used by the HCAL rings	2450 mm
2	*Ecal_endcap_zmax*	z_{max} value of the ECAL endcaps (introduced to avoid overlaps between ECAL and HCAL)	2635 mm
3	*Ecal_endcap_outer_radius*	ECAL endcap outer radius (used by HCAL rings to avoid overlaps)	2088.8 mm
4	*Ecal_outer_radius*	ECAL outer radius (used to calculate HCAL inner radius)	2028 mm
5	*Hcal_apply_Birks_law*	= 1 apply Birks law to the scintillator response, = 0 do not apply Birks law	1
6	*Hcal_back_plate_thickness*	back plate support for the HCAL structure	15 mm
7	*Hcal_barrel_end_module_type*	The Tesla model has a special shape for barrel and end modules: 1 = no special shape, = 2 special shape	1
8	*Hcal_cells_size*	the HCAL cell dimension	30 mm
9	*Hcal_chamber_thickness*	the thickness of the HCAL chambers	6.5 mm
10	*Hcal_digitization_tile_size*	the HCAL tile size used in digitization	30 mm
11	*Hcal_Ecal_gap*	gap between the ECAL and HCAL barrels (used to modify the HCAL inner radius depending on the ECAL outer radius)	30 mm
12	*Hcal_endcap_cables_gap*	gap between barrel and endcaps	214 mm
13	*Hcal_endcap_ecal_gap*	gap between ECAL and HCAL endcaps	15 mm
14	*Hcal_endcap_center_box_size*	size of the central box hole in the HCAL endcap	700 mm
15	*Hcal_fiber_gap*	gap between scintillator and next absorber, which include the 1mm tolerance	2.7 mm
16	*Hcal_lateral_structure_thickness*	lateral support plate thickness	15 mm
17	*Hcal_layer_air_gap*	gap between layer support and scintillator in the HCAL barrel	2 mm
18	*Hcal_middle_stave_gaps*	gap thickness in the middle of HCAL barrel stave	10 mm
19	*Hcal_modules_gap*	gap between HCAL modules in a stave	0 mm
20	*Hcal_nlayers*	number of layers for the HCAL	48
21	*Hcal_radial_ring_inner_gap*	the radial gap between the HCAL ring and and the ECAL endcaps	50 mm
22	*Hcal_radiator_material*	the radiator material ('iron' or 'WMod') 'WMod' is for tungsten	'iron'
23	*Hcal_radiator_thickness*	radiator thickness of the HCAL layers, which includes the 0.5 mm * 2 cassettes	20 mm
24	*Hcal_ring*	= 0, no ring, = 1 LDC like rings (like Tesla TDR)	1
25	*Hcal_sensitive_model*	the sensitive model ('Scintillator' or 'RPC1')	'Scintillator'
26	*Hcal_stave_gap*	gap thickness between the HCAL stave	10 mm
27	*TPC_Ecal_Hcal_barrel_halfZ*	the z-length of the TPC central chamber + the electronics at the bottom (it is also the ECAL barrel size)	2350 mm

Table 1: AHCAL parameters in Mokka Database ILD_o1_v05

2.1 AHCAL Barrel

Updated Tesla Geometry

One eighth of the barrel is called a stave (see Figure 2). In the Tesla model of LDC, it was divided into two modules along the beam axis, i.e. z-axis in the ILD [4] global coordinator system. In the up-to-date engineering design, the $Hcal\_modules\_gap$ was set to "0" from Mokka model "ILD_o1_v05". And this parameter is still used in the Mokka driver for the backward compatibility.

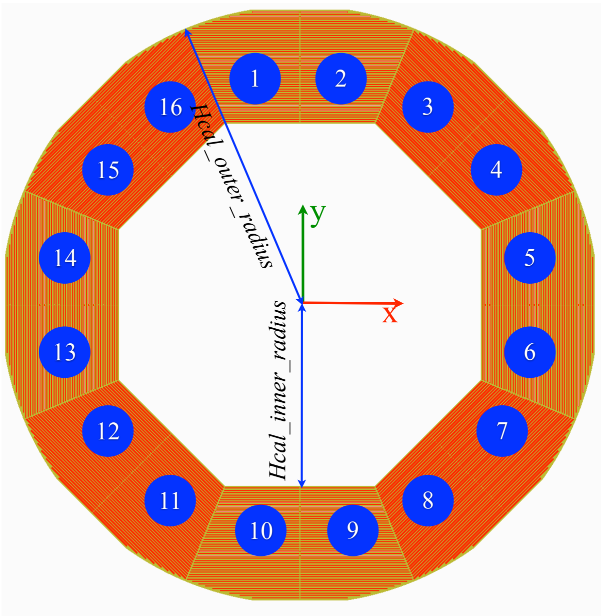

Figure 2: $x - y$ view of the HCAL barrel. The angle of symmetry is $\pi/8$.

The z-dimension of one module is:

$$Hcal\_normal\_dim\_z = (2 \times TPC\_Ecal\_Hcal\_barrel\_halfZ - Hcal\_modules\_gap)/2 \tag{1}$$

The offset $module\_z\_offset$ is needed for a correct positioning of the HCAL modules with respect to the ILD detector's coordinate system, which is situated in the middle of the detector.

$$\text{module\_z\_offset} = \begin{cases} -(Hcal\_normal\_dim\_z + Hcal\_modules\_gap + Hcal\_lateral\_plate\_thickness)/2 & (z < 0) \\ +(Hcal\_normal\_dim\_z + Hcal\_modules\_gap + Hcal\_lateral\_plate\_thickness)/2 & (z > 0) \end{cases} \tag{2}$$

Derivative parameters for AHCAL

The module consists tow part, bottom part has 40 layers, and top part has 8 layers. And the engineering absorber is 19 mm. From the input parameters which are given in the Mokka database and steering file (see Table 1), other parameters can be calculated.

The radius of an AHCAL barrel modules is:

$$\begin{aligned} Hcal\_module\_radius &= (Hcal\_inner\_radius + \\ &\quad (Hcal\_radiator\_thickness + Hcal\_chamber\_thickness) \times 40 \\ &\quad + Hcal\_radiator\_thickness - 1)/cos(\pi/8) \end{aligned} \tag{3}$$

Where

$$\begin{aligned}
Hcal_inner_radius &= Ecal_outer_radius + Hcal_Ecal_gap, && (4)\\
Hcal_total_dim_y &= Hcal_nlayers \times (Hcal_radiator_thickness + Hcal_chamber_thickness) \\
&\quad + Hcal_radiator_thickness - 1 && (5)\\
Hcal_y_dim1_for_x &= Hcal_module_radius \times cos(\pi/8) - Hcal_inner_radius && (6)\\
Hcal_y_dim2_for_x &= Hcal_total_dim_y - Hcal_y_dim1_for_x && (7)\\
Hcal_bottom_dim_x &= 2 \times Hcal_inner_radius \times tan(\pi/8) - Hcal_stave_gaps && (8)\\
Hcal_midle_dim_x &= Hcal_bottom_dim_x + 2 \times Hcal_y_dim1_for_x \times tan(\pi/8) && (9)\\
Hcal_top_dim_x &= sqrt((Hcal_module_radius \times Hcal_module_radius) \\
&\quad -(Hcal_inner_radius + Hcal_total_dim_y) \\
&\quad \times(Hcal_inner_radius + Hcal_total_dim_y)) && (10)
\end{aligned}$$

The derivative parameters are summarised in Table 2.

No.	Parameters name	Default value [mm]
1	Hcal_inner_radius	2058
2	Hcal_module_radius	3395.46
3	Hcal_normal_dim_z	2350
4	Hcal_bottom_dim_x	1694.9
5	Hcal_middle_dim_x	2588.78
6	Hcal_top_dim_x	559.801
7	Hcal_total_dim_y	1291
8	Hcal_y_dim1_for_x	1023.26
9	Hcal_y_dim2_for_x	250.74

Table 2: The AHCAL derivative parameters for the ILD_o1_v05 detector model. Note that the calculation uses the default values in the Mokka data base.

2.2 AHCAL Endcaps

The AHCAL Endcaps provide full solid angle coverage. Figure 3 shows their placement in the layout of the ILD HCAL. Currently, totally updated engineering design has been worked out. And it have been fully implementated in the Mokka driver (SHcalSc03), which also included the electronics front-end readout service. The old simple model has been discarded. A new realistic engineering model with the synchronize engineering design has been implemented in the Mokka driver.

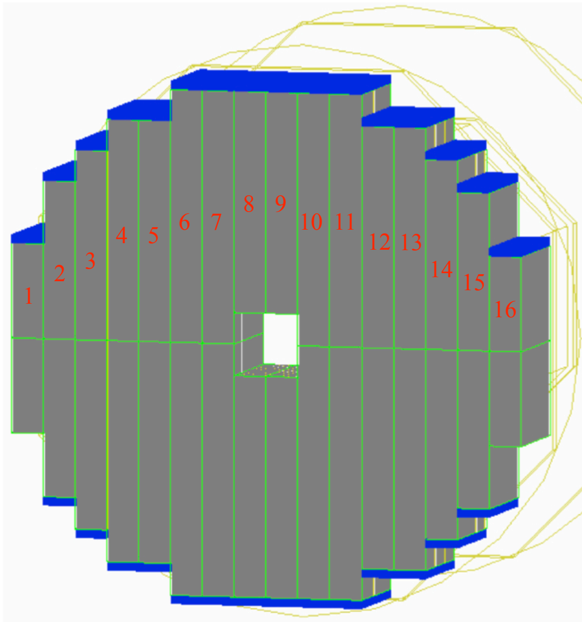

Figure 3: The view of the AHCAL Endcaps. The grey part are the endcap modules consist the absorber and active layers. The blue part are the front-end electronic readout. The most outer tow modules are short enough, and from the practical engineer view, they can be read out with only one front-end electronic readout at one end of the endcaps module.

The placement of the AHCAL endcaps in the z direction is calculated from z limits of the barrel region (ECAL or HCAL) in the following way. First the following values are calculated:

$$\begin{aligned} Hcal\_start\_z &= Hcal\_normal\_dim\_z - Hcal\_modules\_gap/2 \\ &\quad + Hcal\_endcap\_cables\_gaps \end{aligned} \tag{11}$$

$$Hcal\_start\_z = Ecal\_endcap\_zmax + Hcal\_endcap\_ecal\_gap \tag{12}$$

The larger one is used for AHCAL endcaps "$Hcal\_endcap\_zmin$", to avoid an overlap with either Ecal or Hcal barrel. The $Hcal\_normal\_dim\_z$ has been already introduced in section 2.1

The thickness of AHCAL endcaps is calculated:

$$\begin{aligned} Hcal\_endcap\_total\_z &= Hcal\_endcap\_nlayers \times (Hcal\_endcap\_radiator\_thickness \\ &\quad + Hcal\_chamber\_thickness) + Hcal\_back\_plate\_thickness \end{aligned} \tag{13}$$

And the endcap maximium radius was calculated from the 16 endcaps modules, and the maximum one is 3246.93 mm.

No.	Parameters name	Default value
1	Hcal_endcap_module_width	375 mm
2	Hcal_endcap_module_number	16
3	Hcal_endcap_services_module_width	100 mm
4	Hcal_endcap_total_z	1287 mm
5	Hcal_endcap_zmin	2650 mm
6	endcap_rmax	3642.93 mm

Table 3: This table shows both the AHCAL Endcaps engineering design parameters in the Mokka data base, and the derivative parameters calculated from the default value in the Mokka data base.

The geometry parameter, module lengths, are held by a table ("endcap") in the Mokka database ("hcal04"). Note that engineering number can not be changed during the Mokka run time. The detail numbers have been listed in the table 4.

No.	module_length [mm]
1	1087
2	1811
3	2173
4	2536
5	2536
6	2898
7	2898
8	2536
9	2536
10	2898
11	2898
12	2536
13	2536
14	2173
15	1181
16	1087

Table 4: The AHCAL Endcaps engineering design parameters table in the Mokka data base. Note that they can not be changed during the Mokka run time. This table shows the "module_length" in the table "endcap" of Mokka database "hcal04".

The electronic front-end readout service has been implemented within this driver too. They are modeled 0.5 mm thick Cu, 2.8‘mm thick FR4 and 0.5 mm thick steel cassette. They are all the same in width 375 mm and length 100 mm.

2.3 AHCAL EndcapRings

The EndcapRings are implemented to fill the gaps between the HCAL Barrel and the HCAL Endcaps modules. Figure 1 shows their placement in the layout of the ILD HCAL.

Currently, there is no engineering plan for the HCAL EndcapRings. Therefore a simple model in the previous implementation has been inherited, debugged and updated to fit the new ILD geometry.

The EndcapRings had an octagonal shape with an octagonal hole inside to fit the gaps between the Barrel and the Endcaps. The EndcapRings used the more realistic current engineering HCAL chamber layer structure (i.e. identical absorber and active layers as Barrel and Endcaps engineering design).

The dimensions of the EndcapRings are defined by the thickness, the outer radius of the ECAL Endcaps, and the HCAL Endcaps outer radius, to ensure a good coverage in this area.

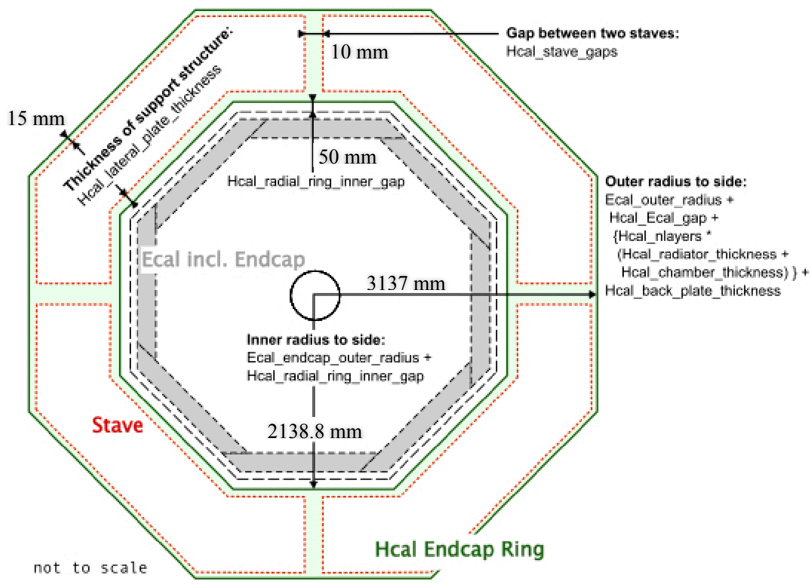

Figure 4: The dimensions of the HCAL EndcapRings. The limits of the endcaps structure are shown in green. The limits of the staves, which correspond to the limits of the sensitive areas, are shown a short dashed, red lines. The ECAL endcaps and barrel are shown in long dashed, grey lines.

Figure 4 shows the geometrical layout and the dimensions of the HCAL endcaps rings in the x-y plane.

The inner and the outer radii of the rings are calculated in the following way:

$$outer\_radius = Hcal\_inner\_radius + Hcal\_y\_dim1\_for\_x \tag{14}$$

$$inner\_radius = Ecal\_endcap\_outer\_radius + Hcal\_radial\_ring\_inner\_gap \tag{15}$$

The dimensions and location of the HCAL endcap rings in z are calculated in the following way:

$$start\_in\_z = Ecal\_endcap\_zmin \tag{16}$$

$$\begin{aligned} number\_of\_layers &= Int[(Hcal\_start\_z \\ &\quad -Hcal\_endcap\_ecal\_gap - Ecal\_endcap\_zmin \\ &\quad -Hcal\_back\_plate\_thickness) \\ &\quad /(Hcal\_chamber\_thickness + Hcal\_radiator\_thickness)] \end{aligned} \tag{17}$$

$$\begin{aligned} thickness\_in\_z &= NumberOfLayers \\ &\quad \times(Hcal\_chamber\_thickness + Hcal\_radiator\_thickness) \\ &\quad +Hcal\_back\_plate\_thickness \end{aligned} \tag{18}$$

No.	Parameters name	Default value
1	Ecal_endcap_outer_radius	2088.8 mm
2	inner_radius	2138.8 mm
3	outer_radius	3137 mm
4	Ecal_endcap_zmin	2450 mm
5	start_in_z	2450 mm
6	Hcal_endcap_zmin	2650 mm
7	Hcal_back_plate_thickness	15 mm
8	Hcal_chamber_thickness	6.5 mm
9	Hcal_radiator_thickness	20.0 mm
10	number_of_layers	6
11	Hcal_endcapRings_thickness	174 mm

Table 5: This table shows both the AHCAL EndcapRings parameters in the Mokka data base, and the derivative parameters calculated from the default value in the Mokka data base.

The EndcapRings can be switched off by setting the parameter *Hcal_ring* to "0" in the steering file at Mokka run time. The default value is "1" in the Mokka data base to build the HCAL EndcapRings.

3 Implementation of AHCAL

3.1 Parameterization of the AHCAL chambers

The three part of AHCAL: Barrel, endcaps, EndcapRings have the common model on the absorber and active layer design. They came from the latest engineering design, which have been model in this way, shown in figure 5.

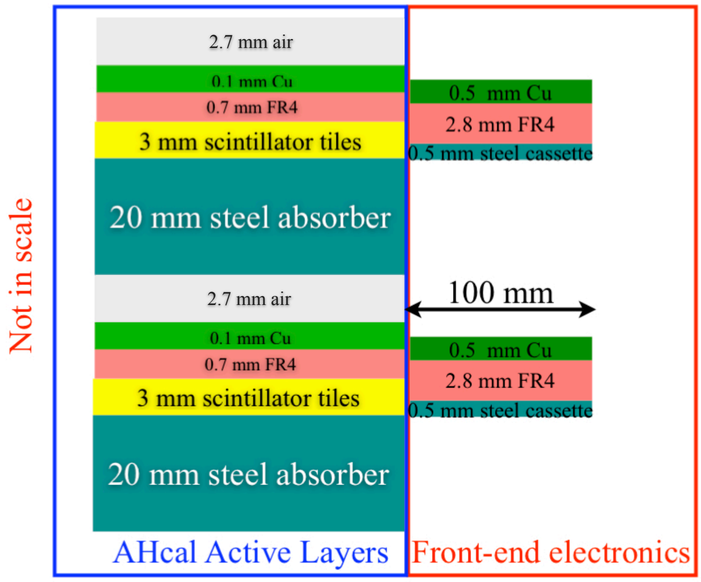

Figure 5: The implementation of the AHCAL layer.

And the chamber thickness is calculated with the following equation:

$$
\begin{aligned}
Hcal\_chamber\_thickness &= Hcall\_scintillator\_thickness + Hcal\_PCB\_thickness \\
&\quad + Hcal\_Cu\_thickness + Hcal\_fiber\_gap \qquad (19)
\end{aligned}
$$

3.2 Sensitive detector

The HCAL cells (i.e. tiles) are only virtually simulated in Mokka. That is, they are not individual Geant4 [5] volumes (which are very CPU time consuming in the case of a calorimeter with millions of cells), but the sensitive volume is virtually divided into cell by coding (digitized cell 30 mm $\times$ 30 mm). It is also very good to avoid touching surface problem in the Geant4 geometry discription.

3.2.1 Cell definition and digitization

The x-dimension of an AHCAL cell is given by the Mokka parameter $Hcal\_cell\_size$ (default 30 mm). For a fixed x-dimension of a stave, they maybe an integer or a fractional number of cells which fit in. From technological point of view, it is impractical to build cells which are less than $Hcal\_cell\_size/2$. To deal with these edge effects, an algorithm to create virtual fractional tiles was used. The resulting fractional tiles have the x-dimension in the domain $[Hcal\_cell\_size/2, Hcal\_cells\_size)$. The creation of the virtual cells starts in the middle of an HCAL layer, such that in the center of the layer there are always integer tiles, and at the edges of the layer there are two fractional tiles (one at each edge).

Another aspect which needs to be considered is the staggering (or the alignment) of the cells within the layers. With the present algorithm, the cells are staggered, and not aligned, such that one needs to take care that the used reconstruction code does not depend on this.

On the y-axis, the dimension of the cell is equal to $Hcal\_scintillator\_thickness$.

Along the z-axis, the cell dimension is set depending on the $Hcal\_cells\_size$ and on the $Hcal\_chamber\_dim\_z$, such that it is always greater than or equal to $Hcal\_cells\_size$:

$$\begin{aligned} Hcal\_cell\_dim\_z \;&=\; Hcall\_regular\_chamber\_dim\_z \\ &\quad /floor(Hcal\_regular\_dim\_z/Hcal\_cell\_dim\_x) \end{aligned} \tag{20}$$

where $floor(Value)$ is a C function which returns the largest integer value smaller than or equal to $Value$, i.e. it rounds down.

The definition of i, j, k coordinate

The coordinates of a cell are given by the geometrical parameters i (on the x-axis), j (on the z-axis) and k (on the y-axis). They are calculated in the sensitive detector class (SDHcalBarrel).

The i-coordinate is calculated as:

$$i \;=\; Int(\frac{x_{local} - X_0 + xOffset}{x_{dimIntCell}}) \qquad for\ left \tag{21}$$

$$i \;=\; Int(\frac{x_{local} - xOffset}{x_{dimIntCell}}) \qquad for\ right \tag{22}$$

where

x_{local} : x-position of the hit in local coordinates system (i.e. in the coordinate system of the HCAL module);

X_0 : equal to minus x-dimension of the layer

$xOffset = Hcal\_middle\_stave\_gaps/2 + Hcal\_layer\_air\_gap$: x offset of the layer, the same for all layers.

$x_{dimIntCell}$: x-dimension of the integer cell.

The j-coordinate is calculated as:

$$j = Int(\frac{z_{local} - ModulesZOffsets[module] - Z_0}{z_{dimIntCell}}) \tag{23}$$

where

z_{local} : z-position of the hit in local coordinates system (i.e. in the coordinate system of the HCAL module);

$ModulesZOffset[module]$: z offset for the respective module, the same for all layers.
Z_0 : equal to minus z-half length of a module
$z_{dimIntCell}$: z-dimension of the integer cells, there are no fractional cells along this direction.

The k-coordinate is equal to the number of the HCAL layer in which the hit is.

The digitized position of the cell center

The position of the simulated hit is set to the position of the cell (i.e. tile) center in the sensitive detector class (SDHcalBarrel), since the dimension of the tile sets the space resolution of the detector.

$x_{cell\ center}$ is calculated as:
For the first cell ($i = 0$):

$$x_{cell\ center} = X_0 - xOffset + x_{dimFractCell}/2 \tag{24}$$

For the last cell:
we know the hit is in the last cell, if $fmod(x_{layer}, temp) == 1$, where

$$x_{layer} = abs(X_0) \tag{25}$$

$$temp = (i-1) \times x_{dimIntCell} + 2 \times x_{dimFractCell}[layer] \tag{26}$$

In this case:

$$\begin{aligned} x_{cell\ center} = & X_0 - xOffset + x_{dimFractCell}Per[layer] \\ & +(i-1) \times x_{dimIntCell} + x_{dimFractCell[layer]}/2 \end{aligned} \tag{27}$$

For all the other cells (except the first and the last one):

$$\begin{aligned} x_{cell\ center} = & X_0 - xOffset + x_{dimFractCell}Per[layer] \\ & +(i-1) \times x_{dimIntCell} + x_{dimIntCell}/2 \end{aligned} \tag{28}$$

where X_0 is the minus length of half x of the sensitive detector in local.

$y_{cell\ center}$ is calculated as:

$$y_{cell\ center} = Y_0 \tag{29}$$

where Y_0 is the distance of the layer from the center of the HCAL module along the y-axis.

$z_{cell\ center}$ is calculated as:

$$y_{cell\ center} = Z_0 + j \times z_{dimIntCell} + z_{dimIntCell}/2 \tag{30}$$

with Z_0 is the minus length of half y of the sensitive detector in local. Note that the $y_{dimIntCell}$ and $z_{dimIntCell}$ has been exchange in the class (SD). So the Y_0 and Z_0 has been exchanged according to this.

The cell encoding and decoding

A new cell encoder/decoder, Encoder32Hcal, was created. The encoding is done as the presented in figure 6.

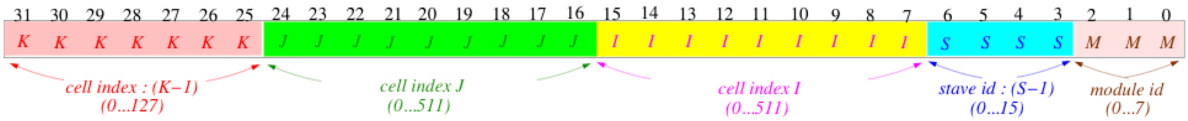

Figure 6: Illustration of the encoding of the HCAL cell indices.

4 Birks Law

Birks law [6] describes the attenuated scintillator response ΔL:

$$\Delta L \propto \frac{\Delta E}{1 + k_B \times dE/dx} \tag{31}$$

where
ΔE - total energy deposit
k_B - Birks constant (material dependent). For polystyrene: $k_B = 0.07943$ mm/MeV. [7]

Birks law was implemented in GEANT4 by Vladimir Ivanchenko (CERN) in class G4EmSaturation. And it has been applied in the AHCAL sensitive detector with parameter $Hcal\_apply\_Birks\_law = 1$ (default value).

5 Mokka GEAR

Mokka GEAR enables to store a higher level description of the subdetector's characteristics for the reconstruction software. It is simplified geometry version, the users can have an view of the detector geometry which they are looking at. Here is one color coded text example, see figure 7. It is needed for running reconstruction job on the Mokka Monte Carlo slcio output file. It is generated at run time by Mokka, and uses XML files for the definition of the subdetector's geometry parameters.

```xml
<detector name="HcalBarrel" geartype="CalorimeterParameters">
    <layout type="Barrel" symmetry="8" phi0="0.000000000e+00" />
    <dimensions inner_r="2.058000000e+03" outer_z="2.350000000e+03" />
    <layer repeat="48" thickness="2.650000000e+01" absorberThickness="2.000000000e+01" cellSize0="3.032467532e+01" cellSize1="3.000000000e+01" />
    <parameter name="Hcal_barrel_end_module_type" type="int" value="1" />
    <parameter name="Hcal_outer_polygon_order" type="int" value="16" />
    <parameter name="Hcal_outer_polygon_phi0" type="int" value="0" />
    <parameter name="Hcal_Cu_thickness" type="double" value="1.000000000e-01" />
    <parameter name="Hcal_PCB_thickness" type="double" value="7.000000000e-01" />
    <parameter name="Hcal_back_plate_thickness" type="double" value="1.500000000e+01" />
    <parameter name="Hcal_lateral_structure_thickness" type="double" value="1.500000000e+01" />
    <parameter name="Hcal_layer_air_gap" type="double" value="2.000000000e+00" />
    <parameter name="Hcal_middle_stave_gaps" type="double" value="1.000000000e+01" />
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    <parameter name="Hcal_scintillator_thickness" type="double" value="3.000000000e+00" />
    <parameter name="Hcal_stave_gaps" type="double" value="1.000000000e+01" />
    <parameter name="Hcal_virtual_cell_size" type="double" value="3.000000000e+01" />
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    <parameter name="Hcal_scintillator_thickness" type="double" value="3.000000000e+00" />
    <parameter name="Hcal_stave_gaps" type="double" value="1.000000000e+01" />
    <parameter name="Hcal_steel_cassette_thickness" type="double" value="5.000000000e-01" />
    <parameter name="Hcal_virtual_cell_size" type="double" value="3.000000000e+01" />
</detector>
<detector name="HcalRing" geartype="CalorimeterParameters">
    <layout type="Endcap" symmetry="2" phi0="0.000000000e+00" />
    <dimensions inner_r="2.138800000e+03" outer_r="3.137000000e+03" inner_z="2.450000000e+03" />
    <layer repeat="6" thickness="2.650000000e+01" absorberThickness="2.220000000e+01" cellSize0="3.000000000e+01" cellSize1="3.000000000e+01" />
    <parameter name="Hcal_Cu_thickness" type="double" value="1.000000000e-01" />
    <parameter name="Hcal_PCB_thickness" type="double" value="7.000000000e-01" />
    <parameter name="Hcal_lateral_structure_thickness" type="double" value="1.500000000e+01" />
    <parameter name="Hcal_scintillator_thickness" type="double" value="3.000000000e+00" />
    <parameter name="Hcal_stave_gaps" type="double" value="1.000000000e+01" />
    <parameter name="Hcal_steel_cassette_thickness" type="double" value="5.000000000e-01" />
    <parameter name="Hcal_virtual_cell_size" type="double" value="3.000000000e+01" />
</detector>
```

Figure 7: One example part of Mokka GEAR for the AHCAL detector which created with ILD_o1_v05 default values.

6 Material tables

In this section, the materials (in Geant4/9.5.p01), which have been used in the driver, have been listed here in detail.

Volume	Parameter	Value [mm]	Comments
Absorber	*Hcal_radiator_thickness*	20	made of Iron (Tab. 11) include 2 cassettes thickness
Cassette	*Hcal_steel_cassette_thickness*	0.5	0.5 × 2, included into absorber
Scintillator	*Hcal_scintillator_thickness*	3.0	made of Polystyrene (Tab. 7)
PCB plate	*Hcal_PCB_thickness*	0.7	Printed Circuit Board (Tab. 8)
Cu plate	*Hcal_Cu_thickness*	0.1	(Tab. 10)
Air gap	*Hcal_fiber_gap*	2.7	pin and cables, tolerance. (Tab. 9)

Table 6: AHCAL layer dimension in Mokka Databse ILD_o1_v05

Polystyrene density = 1.060 [g/cm^3] radiation length = 41.312 cm nuclear interaction length = 68.872 cm					
No.	Material	Atomic number Z	Average atomic mass A [g/mole]	Mass fraction [%]	Abundance [%]
1	Hydrogen	1	1.01	7.74	0.50
2	Cabon	6	12.01	92.26	0.50

Table 7: Composition of the polystyrene material, from which the scintillator tiles are made.

PCB density = 1.700 [g/cm^3] radiation length = 17.505 cm nuclear interaction length = 48.424 cm					
No.	Material	Atomic number Z	Average atomic mass A [g/mole]	Mass fraction [%]	Abundance [%]
1	Silicon	14	28.09	18.08	5.20
2	Oxygen	8	16.00	40.56	20.50
3	Cabon	6	12.01	27.80	18.72
4	Hydrogen	1	1.01	6.84	54.90
5	Bromine	35	79.90	6.71	0.68

Table 8: Composition of the PCB (Printed Circuit Board) material, of type FR4, in the AHCAL description.

Air density = 1.205 [g/cm^3] radiation length = 30392.1 cm nuclear interaction length = 71026.1 cm					
No.	Material	Atomic number Z	Average atomic mass A [g/mole]	Mass fraction [%]	Abundance [%]
1	Cabon	6	12.01	0.01	0.02
2	Nitrogen	7	14.01	75.53	78.44
3	Oxygen	8	16.00	23.18	21.07
4	Argon	18	39.95	1.28	0.47

Table 9: Composition of the Air material in Geant4, which is used in the AHCAL description.

Copper (Cu) density = 8.960 [g/cm^3] radiation length = 1.436 cm nuclear interaction length = 15.514 cm				
No.	Material	Atomic number Z	Average atomic mass A [g/mole]	Abundance [%]
1	Isotope Cu63	29	62.93	69.17
2	Isotope Cu65	29	64.93	30.83

Table 10: Composition of the copper (Cu) material in Geant4, which is used in the AHCAL description.

Iron (Fe) density = 7.874 [g/cm^3] radiation length = 1.757 cm nuclear interaction length = 16.959 cm pion interaction length = 20.42 cm				
No.	Material	Atomic number Z	Average atomic mass A [g/mole]	Abundance [%]
1	Isotope Fe54	26	53.94	5.84
2	Isotope Fe56	26	55.93	91.75
2	Isotope Fe57	26	56.94	2.12
2	Isotope Fe58	26	57.93	0.28

Table 11: Composition of the Iron (Fe) material in Geant4, which is used in the AHCAL description.

7 AHCAL depths in the units X_0^e and λ_I^e

The radiation length $X_0^{effective}$ [8] in a mixture or compound may be approximated by:

$$\frac{1}{X_0^{effective}} = \sum_i \frac{V_i}{X_0^i} \tag{32}$$

where V_i is the fractional volume of the material i, and X_0^i is corresponding radiation length in the unit [mm].

And the nuclear interaction length $\lambda_I^{effective}$ is calculated by:

$$\frac{1}{\lambda_I^{effective}} = \sum_i \frac{V_i}{\lambda_I^i} \tag{33}$$

where λ_I^i is corresponding nuclear interaction length.

For one AHCAL layer:

Layer element	Thickness [mm]	Material	X_0 [mm]	λ_I [mm]
Absorber	20	Iron	17.57	169.59
Scintillator	3.0	polystyrene	413.12	688.72
PCB plate	0.7	FR4	175.05	484.24
Cu plate	0.1	Cu	14.36	155.14
Air gap	2.7	Air	303921	710261

Table 12: Thickness, material and corresponding radiation lengths of an AHCAL layer.

For one layer of AHCAL in the barrel, Endcaps and EndcapRings, the radiation length is $X_0^e = 22.9$ mm, and the interaction length is $\lambda_I^e = 213.05$ mm.

For the whole AHCAL Barrel, Endcaps and EndcapRings:

AHCAL layer pitch thickness = 26.5 mm density = 3.299[g/cm^3] radiation length $X_0^e = 22.913$ mm nuclear interaction length $\lambda_I^e = 213.054$ mm			
AHCAL	Total thickness [mm]	Depth in [X_0^e]	Depth in [λ_I^e]
Barrel	1291 (1167.9 - 1308.9)	56.3 X_0^e (50.9 - 57.1)	6.06 λ_I^e (5.48 - 6.14)
Endcaps	1287	56.2 X_0^e	6.00 λ_I^e
EndcapRings	174	7.6 X_0^e	0.82 λ_I^e

Table 13: The depth of the whole AHCAL. For the Barrel part, the variation of the depth is from minimum 50.9 X_0^e or 5.48 λ_I^e at $\pi/8$, and maximum 57.1 X_0^e or 6.14 λ_I^e around $\pi/16$. (see figure 2)

8 An overview of AHCAL boundaries in the ILD

In this section, an overview of the boundaries of AHCAL in the ILD detector has been summarized in figure 8. It shows where the AHCAL is in the current Mokka "ILD_o1_v05" model, and relative position and gaps to the inner ECAL and outer Coil and Yoke.

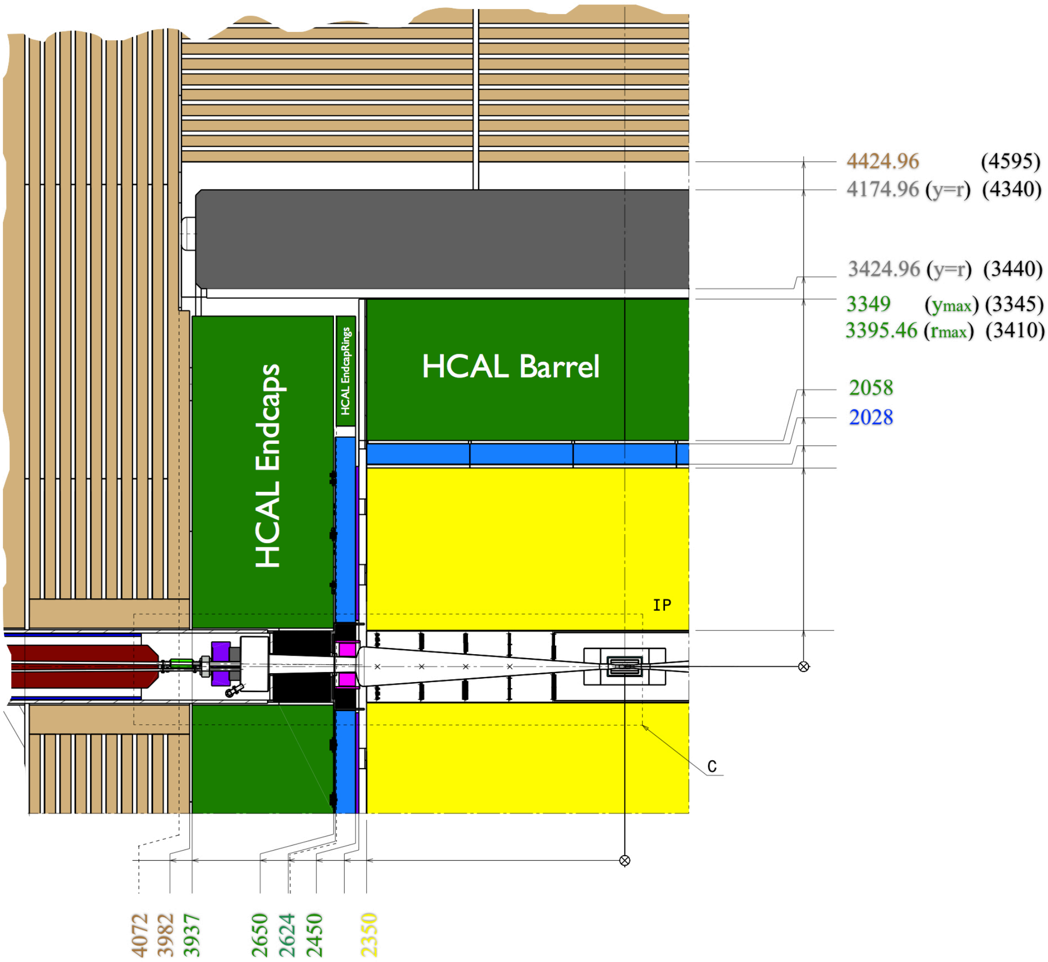

Figure 8: AHCAL boundaries built with ILD_o1_v05 default values. The AHCAL Barrel outer shape has been updated to the latest engineering design (see figure 2), and it has a round shape, which changed the outer radius from 3410 mm to 3395.46 mm. And the gap between AHCAL and Coil is 29.5 mm (3424.96 − 3395.46). In the z-direction, there is 100 mm (2450 − 2350) services between AHCAL Barrel and the EndcapRings, and the EndcapRings thickness is 174 mm (see section 2.3). There is a 45 mm (3982 − 3937) gap between AHCAL Endcaps and Yoke Endcap Plug (thickness is 90 mm, i.e. 4072 − 3982), if the Yoke Endcap Plug is built with "Plug" is "ture".

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