A new version of the Digital Hadron CALorimeter in MOKKA

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Abstract

We present in this document a new implementation in MOKKA of a Digital Hadron Calorimeter for the LDC concept. It consists of a totally new geometry for the barrel, and makes use of improved RPC description. The end-caps are left unchanged compared to the previous TESLA TDR design.

Contents

1 Previous version of the DHCAL

The version of the HCAL used so far in MOKKA was the one of the Tesla TDR, see [1]. The documentation of its implementation in MOKKA can be found at [2].

To give a brief summary, this HCAL was composed of (see Fig.1):

- a barrel surrounding the Ecal, divided into 8 staves, each stave being divided into 5 modules of 40 layers;
- an end cap closing each side of the barrel.

This model was used both for AHCAL and DHCAL: the active detector was just changed between scintillator for the former and RPC for the latter.

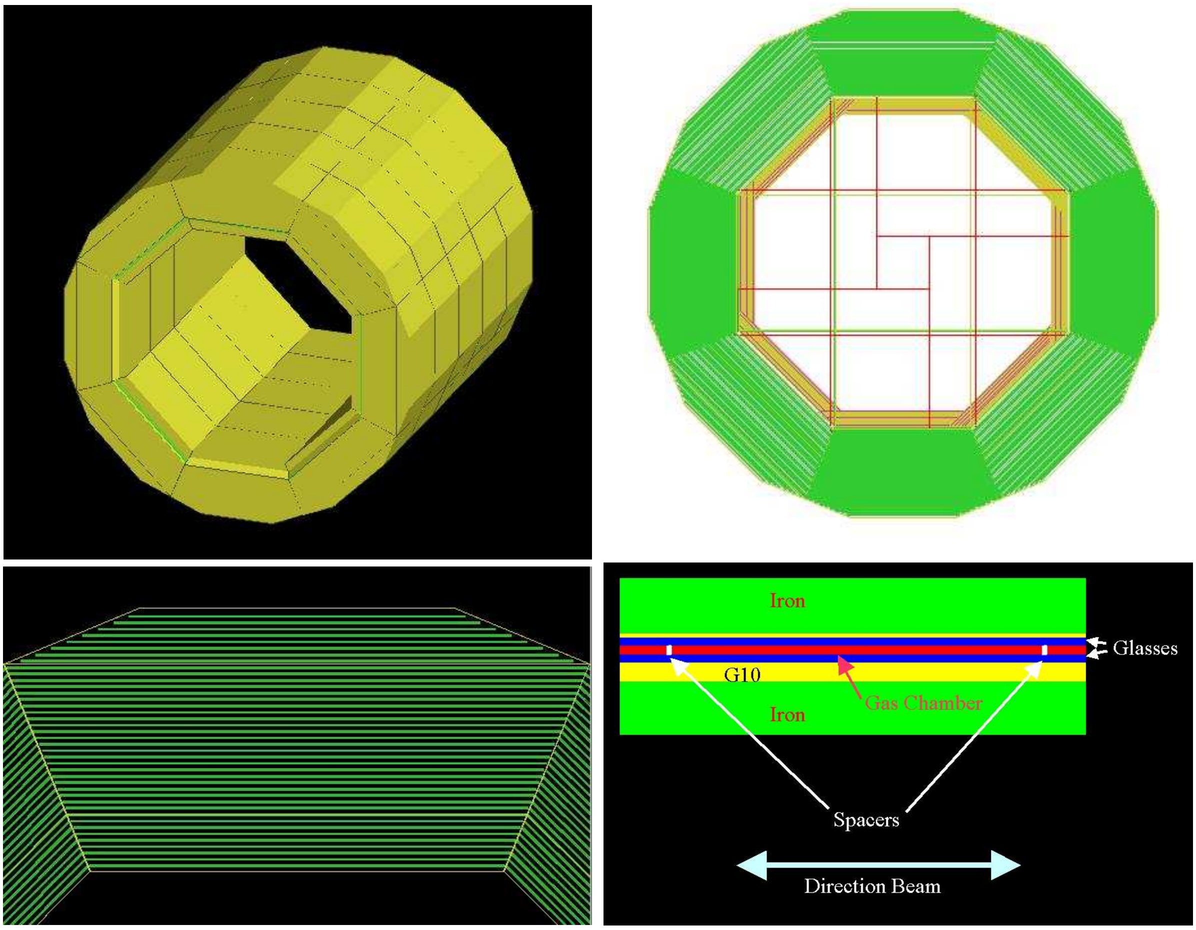

Figure 1: Description of the old Tesla model for the HCAL: the barrel (top left), the end-caps (top-right), a module (bottom left) and the RPC model (bottom right). Taken from [2].

It was implemented in a driver called `Hcal03`, in `models03`. The code is located in: `Mokka/source/Geometry/Tesla/`. The RPC model was implemented in `hcalFeRpc1`.

2 New version of the DHCAL

In order to improve the description of the DHCAL for the mass generation of Monte Carlo samples and allow detector optimization studies, we have implemented a new version of the DHCAL:

- it contains a completely new geometry for the barrel, as proposed by Henri Videau. This is introduced in section 2.1;
- it uses new RPC for the active detectors, described in section 2.2;
- materials used were updated to match those used in the actual DHCAL R&D studies (section 2.3);
- the sensitive detector was adapted to this new model, as explained in section 3.4

The end caps, for which no new ideas were suggested, were kept as in the Tesla TDR.

2.1 Geometry

The new geometry implemented for the barrel[1] of this DHCAL was proposed by Henri Videau. It is shown on Fig. 2.

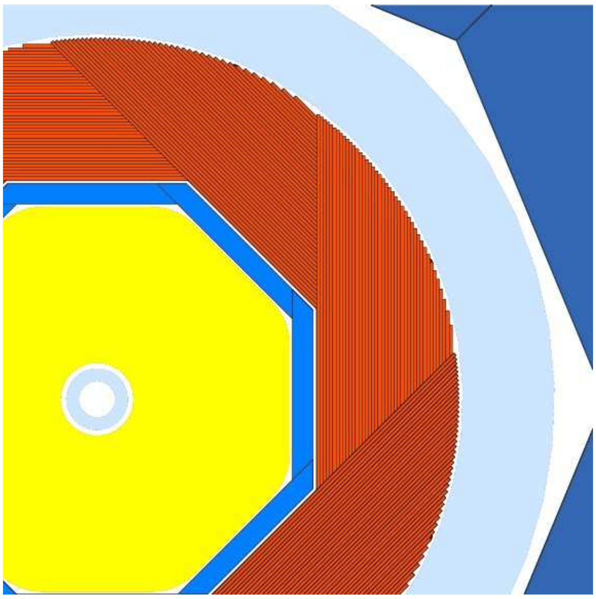

Figure 2: DHCAL barrel geometry *à la Videau*.

It is composed of 5 modules, each containing 8 staves composed of 40 layers. This geometry presents the advantage of not containing any crack between the staves nor in the plan normal to the z axis and containg the interaction point. Furthermore it is particularly convenient for gas supply and electronic readout for which connections can be positioned completely outside the barrel. Note however that studies on the mechanical structure will have to be performed so as to ensure that this configuration is technically realistic.

2.2 Active detectors: Resistive Plate Chambers

The Resistive Plate Chambers included in this model are inspired by those currently under development in the european DHCAL group.

The chamber, as can be seen on fig. 3, is composed of the following components:

- high voltage layers are made of graphite of 50 μm on the anode side and 100 μm on the cathode side;
- insulator layers are made of layers of 100 μm on the anode and 100 μm on the cathode side;

[1]We recall here that the end-cap used are those of the TESLA TDR.

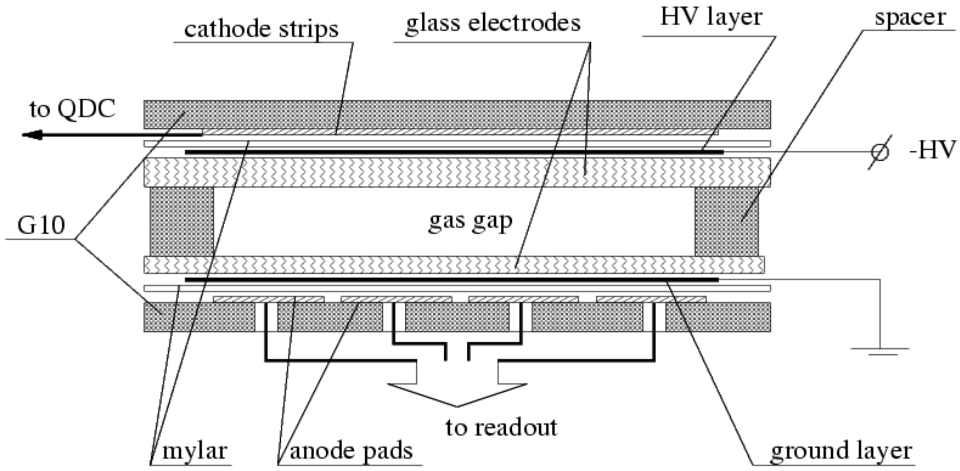

Figure 3: RPC scheme.

- a gap of 1.2 mm of thickness;
- two glasses enclosing the gap, of 700 μm on the anode and 1.1 mm on the cathode side;
- a frame enclosing the gap an supporting the glasses, of 1.2 mm of thickness, and 3mm of width,
- a PCB that contains the read-out pads
- a layer of read-out electronics above the PCB, made of HardRoc ASICs and a mask of PCB around the ASICS to have a homogeneous structure;
- five spacers, separated by 15 cm, located inside the gap, and with a length of three quarters of the gap length;
- two outlets for the gas, of outer diameter 1mm and inner diameter of 800μm, are placed through the frame for gas renewal.

The total thickness budget for the RPC is foreseen to be 6 mm. The current list of materials adds up to 5.6 mm. The 400 μm margin left is so far filled with air.

2.3 Materials

The R&D developments in the DHCAL required to update the Mokka material database (DB). The new materials have been added to the `materials02` database.

2.3.1 Absorber

The absorber used for the barrel is now stainless steel.

2.3.2 RPC

The list of materials used for the RPC is given in table 1. Some of them were already available the database. This was the case for mylar, graphite, and g10.
However, a few materials needed to be added. A new mixture is used for the RPC gas. The glass is also different: we use *float glass* instead of pyrex. Fishing line are no longer g10 but nylon.
The electronics situated above the PCB, which contains the HardRoc ASICS, is physically made of a thin slice of Si, and most of its material is coming from the TQFP packaging, very similar to g10. Since one would use a mask complementary to the ASIC around it to have an homogeneous detector, which would be made of g10 too, the whole eletronics layer was modeled by a simple layer of g10.

Component	Material	Name of material in DB
PCB+Electronics	G-10/FR4 epoxy	g10
mylar	mylar	mylar
graphite	graphite	graphite
glass	quartz+soda+Mg0+CaO	FloatGlass
gas	Mixture: TFE(93%)+SF_6 (2%)+isobutane (5%)	RPCGAS2
spacers	nylon	nylon
frame, gas inlets	PEEK-GF30 (PolyEtherEtherKetone+30% glass fiber	PEEK
free space	air	air

Table 1: List of materials used for the RPC in the new DHCAL model.

3 Implementation

This new model was implemented in the LDC concept (`Mokka/source/Geometry/LDC/`) in the superdriver `SHcal04`, and will be included in the Mokka release 06.06. It is largely based on the previous `SHcal03` superdriver.

3.1 Parameterization of the RPC chambers

The whole geometry can be parameterised with only three parameters:

- the number of layers inside a module (we take 40);
- the outer radius of the DHCAL (r' on Fig.4);
- the distance between the center of the detector and the first plate of the DHCAL (h' on Fig.4).

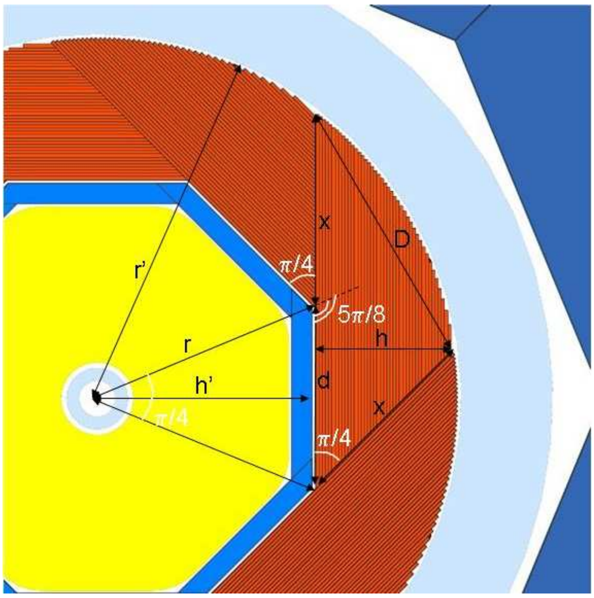

Figure 4: Parameterization of the barrel geometry.

From these parameters, we can deduce:

$$d = kr \quad (1)$$
$$D = kr' \quad (2)$$
$$h = x/\sqrt{2} \quad (3)$$

$$h' = \sqrt{r^2 - d^2/4} \quad (4)$$

$$x = \frac{\sqrt{2D^2(2+\sqrt{2}) - d^2(3+2\sqrt{2})} - d}{2} \quad (5)$$

with $k = \frac{sin(\pi/4)}{sin(3\pi/8)}$.

3.2 Definition of the barrel

The implementation of this new geometry is done in a new superdriver called `SHcal04`, located in `Geometry/LDC/`. The logical volume of the barrel, built in `SHcal04::Barrel(...)`, is a boolean solid, made of the subtraction of an octogon from a G4Tub. It is filled with the absorber material, made of stainless steel.

Although the barrel physically contains five modules of eight staves, the concept of module and stave does not really exist in the implementation of the barrel. Instead it is build in `SHcal04::BarrelVirtualModules(...)` the following way:

- a layer is placed in the reference stave[2]. The orientation adopted in building the RPC chamber is shown on the top left frame of Fig.5: thickness is along x-axis, fixed large dimension is along y-axis and variable large dimension is along z-axis.
- therefore the layer is then rotated as shown on Fig.5 to put it in the proper position in stave 0, module 0 (stave 0 is the stave oriented horizontally on the top of the DHCAL, and module 0 the module placed at the foremost position in the negative direction of the z-axis);
- the layer is filled with a RPC;
- the layer is propagated to the eight staves by successive rotations $+\pi/4$ around the z-axis, in the trigonometric sense;
- these eight layers are then propagated to the fives modules with an offset in the positive direction of the z-axis;
- the same procedure is then repeated by looping on all the layers.

Each volume placed is given a copy number, with the following format:

```
copynb=1000*stave_id+100*module_id+HCALBARREL
```

The size of each layer is computed in `SHcal04::BarrelVirtualModules(...)` by $yn + Yn$:

- yn is the distance between the outer extremity of an RPC (extremity located at r') and the intersection point between the RPC and the normal to the RPC passing through the center of the calorimeter.
- Yn is the rest of the RPC, i.e. the distance between the extremity of the RPC (extremity inside the calorimeter) and intersection point between the RPC and the normal to the RPC passing through the center of the calorimeter.

3.3 Definition of the RPC

The improved RPC description is implemented in `SHcal04::BuildRPC2Box(...)`. A Geant4 representation[3] is given on Fig.6. A cross section of this Geant4 model is given in Fig.7.

The RPC consists of a logical volume defining the whole chamber, placed inside the solid G4Box that is given as a parameter of `SHcal04::BuildRPC2Box(...)`. The different components are then placed individually inside this logical volume, starting from the g10 layer modeling the electronics. Then the PCB is included, at a position defined relatively to the electronics layer. Following the same scheme, the other elements of the chamber are then placed with respect to the element placed just before the one considered, so as to avoid any geometrical overlap between the volumes.
A sensitive detector, described in more details in section 3.4, is associated to the RPC gap.

[2] The reference stave is the stave on which the dimensions have been specified on Fig.4

[3] Beware! Scale is not respected in this picture: length and width have been reduced to allow the other elements to be visible.

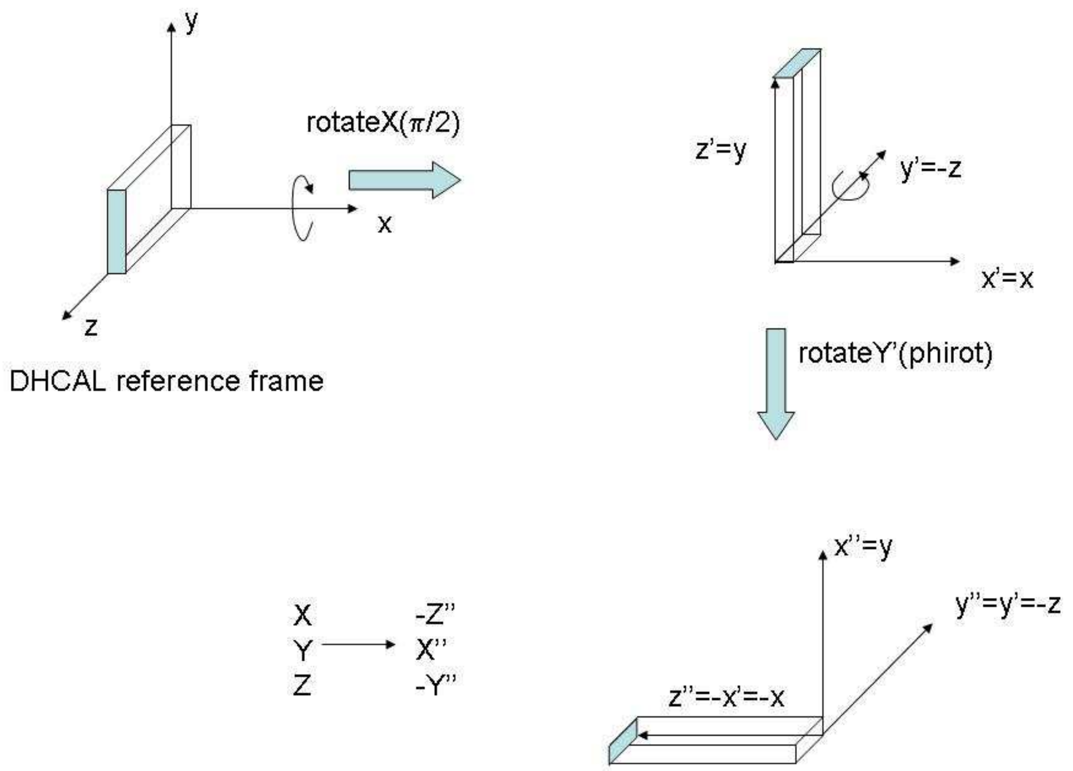

Figure 5: Operations used to position the RPC from the reference module to the stave 0 of module 0. Spacers are oriented in a direction parallel to the large side of the blue area.

3.4 Sensitive detector

3.4.1 Sensitive volume

The sensitive detector is implemented in `SDHcalSD01`, located in `Geometry/LDC/`. The sensitive volume is associated to the logical volume of the gap. In the DHCAL reference frame (top left frame in Fig.5), the center of the logical volume is located in the xy plan at (localXpos,localYPos). Note that the center of the gap does not correspond to the center of the RPC, but is shifted in x-direction (lab frame) by RPC_GapPosX, because the RPC is not symmetric. The size of the sensitive detector in the yz plan is (Yn+yn-2*RPC_EdgeWidth,Hcal_normal_dim_z-2*RPC_EdgeWidth).

The spacers, which are daughters of the gap, are not included in this sensitive volume, so that only energy deposits located inside the gas generate recorded hits. The origin of the sensitive volume is located at one corner of the gap, at (X0,-moduleZOffset,Y0).

3.4.2 Cell definition

The recorded hit information is the same as the one that was previously used in `SHcal03`, since the same `CalHit` class is used. In particular, only the center of the cell in which energy was deposited and the cellID are recorded, and not the exact location of the deposit.
The cell definition is similar to the one used in the previous Hcal version. It is made of five integers:

- M: locates the module, $M = 1...5$;
- S: locates the stave, $S = 1...8$;
- K: locates the layer, $K = 1...40$;

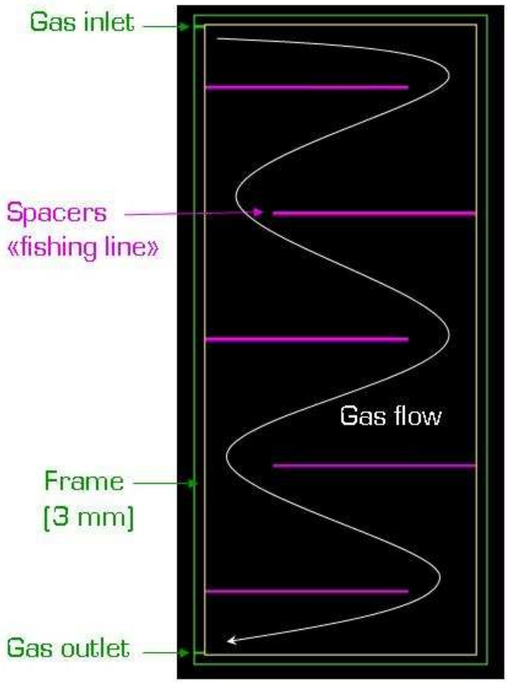

Figure 6: Geant4 modelisation of the improved RPC.

- I: local coordinate relative to the chamber (y-axis direction in DHCAL reference frame, see Fig.5);
- J: local coordinate relative to the chamber (z-axis direction in DHCAL reference frame).

The position of the hit, defined in the three-vector `thePosition` as the middle of the step[4], is first converted to local coordinates in the reference module, by applying the inverse of the rotation used to place the layer. This local position, stored in three-vector `localPosition`, is then shifted by (X0, ModuleZOffsets[theModule], Y0) to compute its coordinates relatively to the origin of the sensitive volume. **Beware to the possible confusion here!** The third component of `localPosition` is shifted by Y0. This is normal since localYPos is defined by $-Yn + 0.5 * (Yn + yn)$, so it corresponds to the z-axis in the local frame, not the y-axis. Same remark applies to the second component of `localPosition`.

The I and J integers that identify the cell in the local frame are then calculated. They are defined such that I increases when x coordinates increase and J increases for increasing z coordinates.
The local cell center is computed in `SDHcalSD01::GetCellCenter` and the cell center is obtained in the lab frame by applying the inverse rotations used to go from the lab to the RPC frame.

In the DHCAL, cells are expected to be of 1cm×1cm. However, in order to be more realistic with what the electronic readout will be, a gap is placed between the pads (Fig.8). It is fixed by default at 500 μm, but this value could evolve in the future. The cell dimension is stored in a three-vector called `CellDim`.

3.5 Use of the code: steerable parameters

To use this new calorimeter, you have to include it in your MOKKA steering file with:

[4]mean between the PreStepPoint and the PostStepPoint positions, taken in the World reference frame.

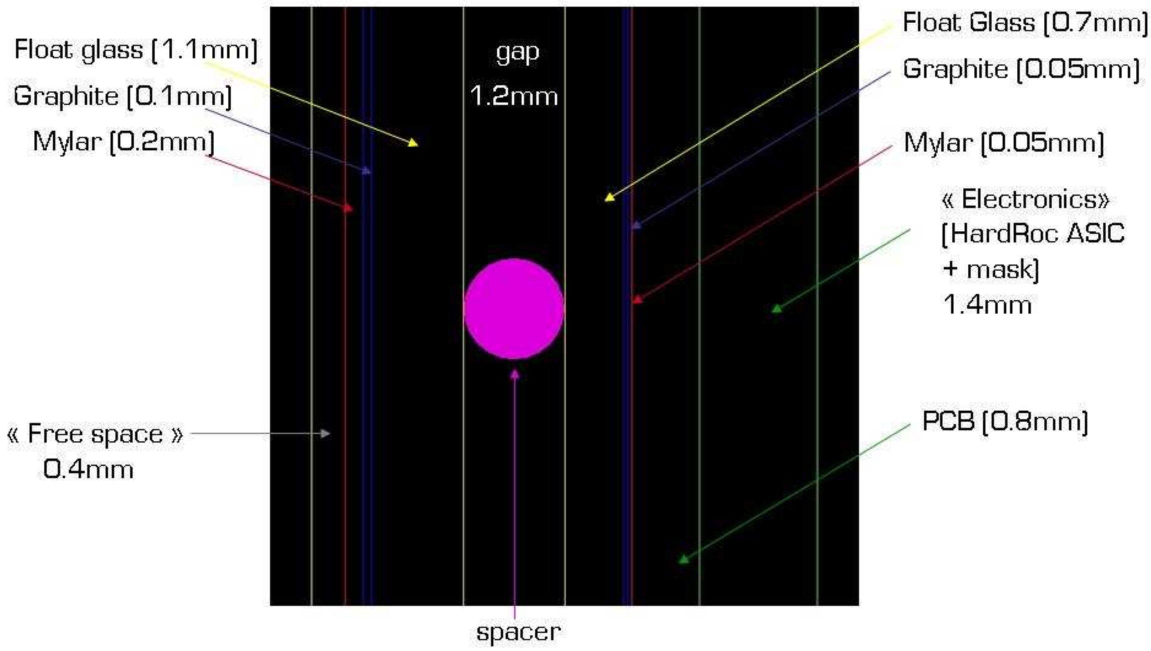

Figure 7: Cross section of the Geant4 modelisation of the improved RPC.

/Mokka/init/subDetector SHcal04
which will build only the DHCAL, with the new barrel and the old end-caps.

An example of a 20 GeV π^- shot from $(0, 0, 0)$ in the $(0, 1, 0)$ direction is given on Fig.9.

The list of parameters of the DHCAL are listed in the table `parameters` of the `models03` DB, that contains their name, their description and their default value. These parameters are then associated to the superdriver, and if a value of the parameter exists in the `sharing` table, the value of the parameter is changed to this value. The `model_parameters` table can also contain some values for these parameters, specific to some detector models. If a value of a parameter is assigned to a parameter in this table, then this value supersedes the previous ones (from `sharing` and `parameters`). Eventually, these parameters can be changed in the MOKKA steering file.

3.6 MokkaGEAR

MokkaGEAR enables to store a simplified geometry version for the reconstruction software. **This part has to be done.**

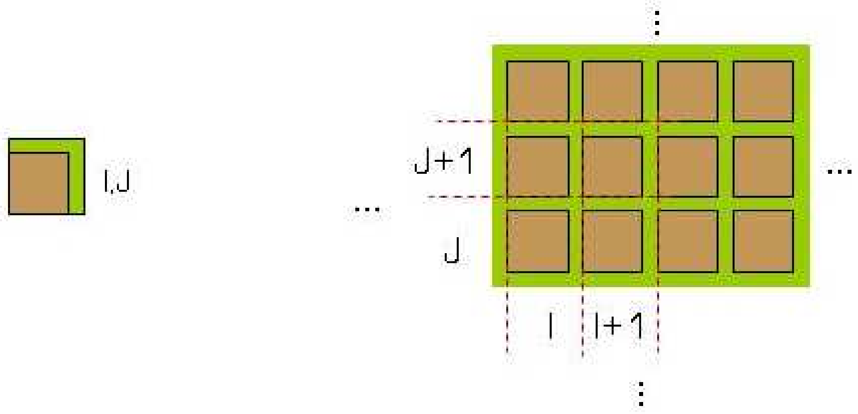

Figure 8: Representation of a cell (left plot) used in the DHCAL, composed of a 1cm× 1cm pad (brown), and a gap of 500μm (green), and of the grid of cells (right plot) as disposed on the PCB.

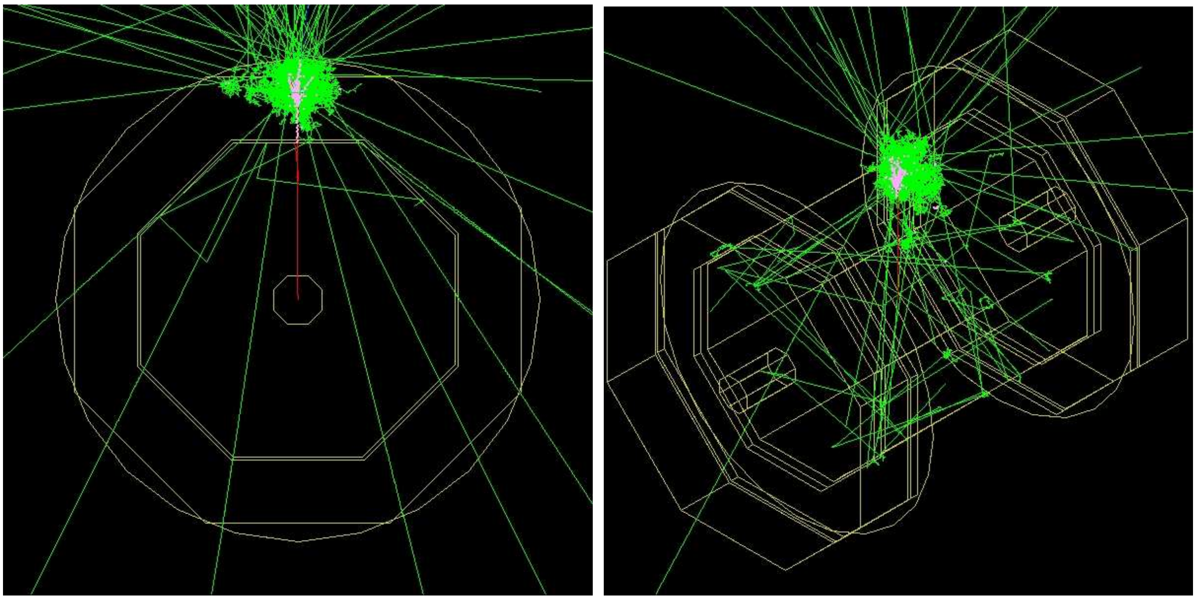

Figure 9: A 20 GeV π^- event shot from $(0, 0, 0)$ in the $(0, 1, 0)$ direction, and viewed from the normal to the z-axis (on the left) and to normal of the $(1, 1, 1)$ axis (on the right).

References

[1] http://tesla.desy.de/new_pages/TDR_CD/start.html

[2] http://polywww.in2p3.fr/activites/physique/geant4/tesla/www/mokka/hcal/hcal.html