Proposal of a new Hcal geometry avoiding cracks in the calorimeter

N. Geffroy, C. Girard, Y. Karyotakis, M. Oriunno, M. Breidenbach, K. Krempetz

Laboratoire d'Annecy-le-Vieux de Physique des Particules

LAPP-TECH-2008-02
September 2008

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N. Geffroy, C. Girard, Y. Karyotakis
LAPP Laboratoire d'Annecy-le-Vieux de Physique des Particules
Université de Savoie CNRS/IN2P3
BP. 110, F-74941 Annecy-le-Vieux Cedex, FRANCE
Phone: +33-4-50-09-16-00, Fax: +33-4-50-27-94-95, E-mail: nicolas.geffroy@lapp.in2p3.fr

M. Oriunno, M. Breidenbach
SLAC
Stanford Linear Accelerator Center
2575 Sand Hill Road, Menlo Park, CA 94025, USA
Phone : +1-650-926-3300, E-mail: oriunno@slac.stanford.edu

K. Krempetz
Fermilab, Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, IL 60510-5011, USA
Phone : +1-630-840-3000, Fax : +1-630-840-4343, E-mail: krempetz@fnal.gov

Abstract

The classical geometry of a calorimeter consists most of the time in several modules, whose edges are pointing on the beam axis. Thus, detection discontinuities between two consecutive modules induce cracks in the calorimeter, and consequently a loss of precious information.

This paper describes two new possible Hcal geometries avoiding such cracks in the detection. Then it deals with the internal layout and assembly procedure.

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I. INTRODUCTION

A calorimeter is made to detect particles emitted from the interaction point. It looks like a cylindrical structure centered on the interaction point, whose axis is the beam axis, and whose cross-section can be compared to a closed hollow circle. Actually, it is made up of several modules and the transverse section of the classical configuration consists (most of the time) in twelve identical trapezoidal modules (cf. Figure 1).

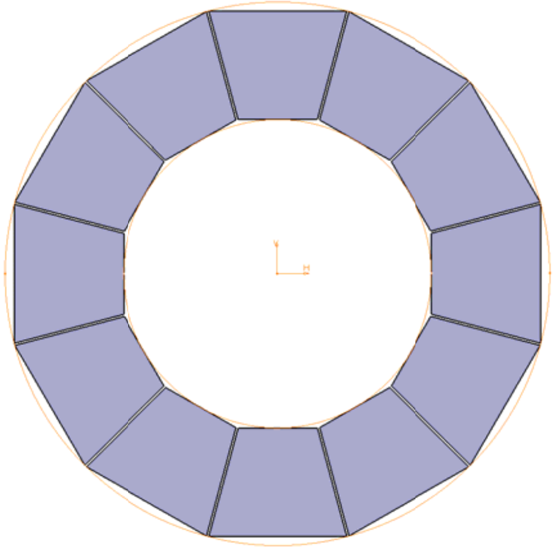

Figure 1: classical geometry

The space between two consecutive modules due to mechanical reasons creates discontinuities in the detection. Indeed detection chambers are only distributed inside the modules, and given that the latter have edges pointing on the beam axis, some particles can cross the calorimeter without being detected: “cracks” exist in the structure.

The two geometries presented below overcome this point. Indeed they are based on the non-alignment of the module edges on the beam axis, that is to say on tilted edges.

II. FIRST HCAL GEOMETRY PROPOSAL

A. Principle.

In order to avoid cracks the module edges should not point to the axis of the barrel. This first configuration is tilted using the following method: the edges of every module are tangent to the same circle (cf. Figure 2). The circle radius is the only parameter which dictates the tilt level, and modules are consequently all the same.

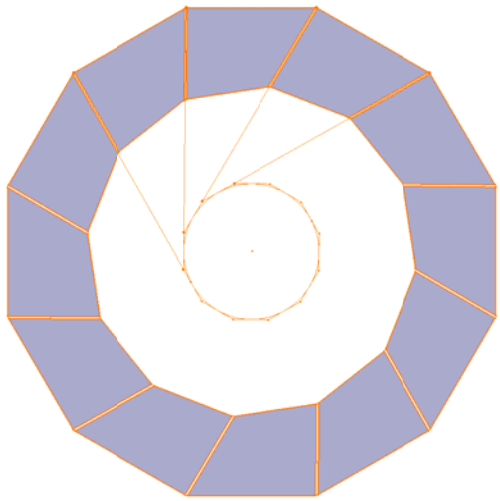

Figure 2: First tilted geometry

B. Tilt level

The tilt level is a function of the circle radius. The minimum value of the latter is equal to zero (no tilt: classical geometry), whereas the maximum value is identically equal to the internal radius of the barrel (maximal tilt). Figure 3 illustrates the evolution of the tilt level.

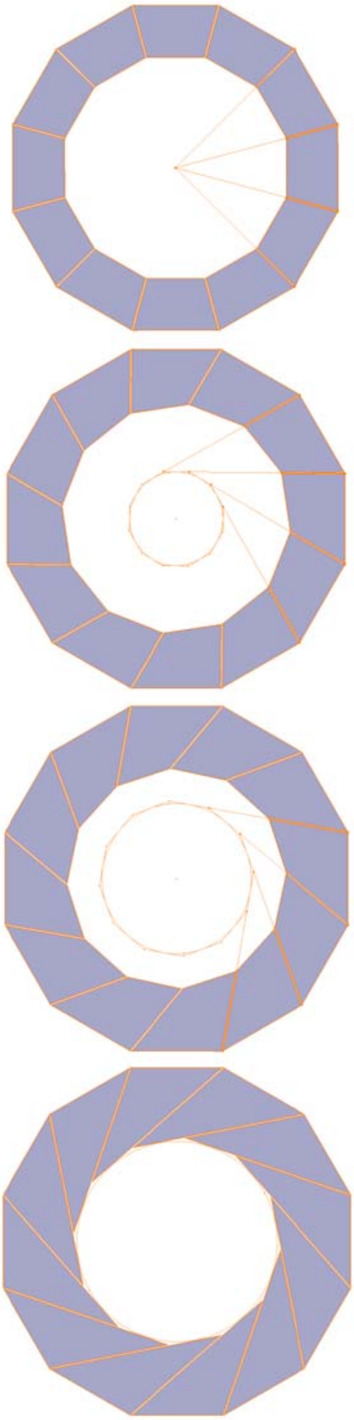

Figure 3: Evolution of the tilt level (from the classical geometry to the maximal tilted configuration)

C. Comments

The modules do not keep the same shape when the tilt is modified. Consequently the calorimeter minimal thickness must be adjusted in order to always obtain the same number of interaction lengths. Moreover, for a given calorimeter minimal thickness, the barrel external radius varies when the tilt value is modified.

Figure 4 shows the variation of the external radius as a function of the tilt level, for three arbitrary minimal thicknesses. Nevertheless it appears that there is always an optimal tilted configuration for which the external radius is the same than the not-tilted configuration.

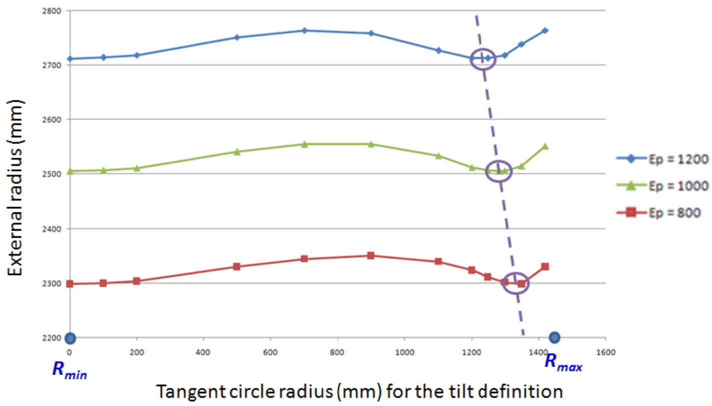

Figure 4: Evolution of the external radius as a function of the tilt level, for three different minimal calorimeter thicknesses.

III. SECOND HCAL GEOMETRY PROPOSAL

A. Principle

The method used for the second version is quite similar to the first one. A circle is still used for the tangency of the edges. Nevertheless the two opposite edges of each module are tangent to the circle, but in an opposite way: the 2 points of tangency correspond to a diameter of the circle. Figure 5 illustrates the method. Thus all the modules are not identical: two different shapes are created.

B. Tilt level

For this second solution, the tilt level is depending on the circle radius as well. Some examples of tilted configurations are presented in Figure 5.

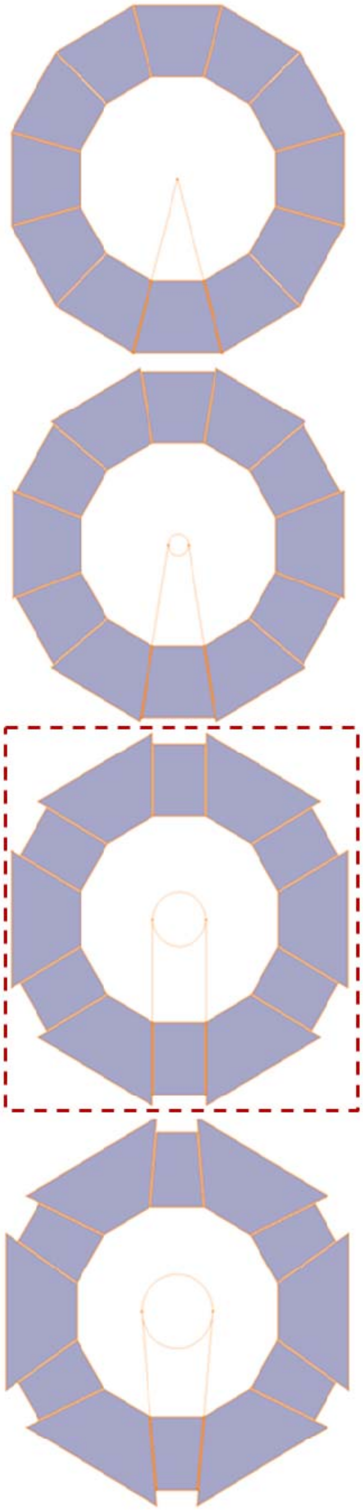

Figure 5: Evolution of the tilt level for the second configuration

C. Comments

Note that like the first geometry, the barrel external radius increases with the tilt level. Furthermore, two groups of trapezoids are thus generated, excepted for a specific value of the circle diameter, corresponding to one edge of the internal dodecagon (cf. 3rd picture in Fig. 5). For this configuration, six modules are rectangles, the six others are trapezoids.

IV. THE FAVORITE HCAL GEOMETRY

A. Introduction

Among these two versions, a great choice of tilted modules is possible. Nevertheless, the second geometry, especially the one with rectangles and trapezoids, seems to be more appropriate thanks to the symmetry, both of each module and of the global structure. Symmetric parts are mechanically more interesting. Indeed, stresses and strains will be symmetric (although depending on boundary conditions), and solutions to overcome eventual problems will be easier to find and to adopt.

B. An optimized geometry

Furthermore, the Hcal external radius, that is to say its overall dimension, which dictates the size of the magnet and of the muon detector, is a parameter of prime importance, in terms of cost to name but a few… To reduce the external radius to its minimal dimension is therefore primordial, the minimal overall dimension being the projective geometry (Figure 1). An illustration of the tilted and optimized configuration is shown on Figure 6.

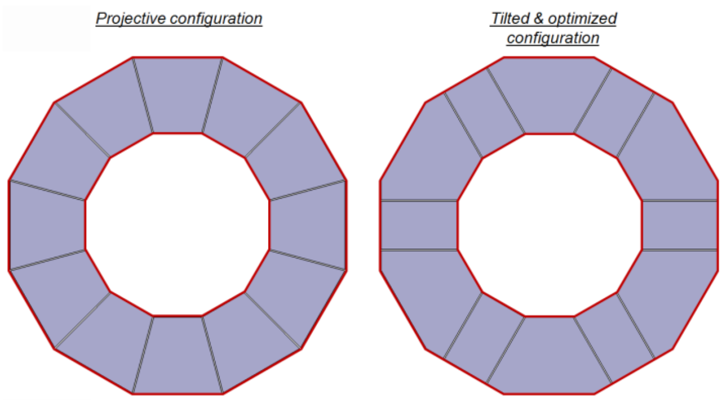

Figure 6: Comparison between projective and optimized tilted geometry

The tilted and optimized configuration comes from the geometry with 6 rectangles and 6 trapezoids. The tips of the trapezoidal modules have been "cut off". As a consequence, the internal and external boundaries of both geometries are exactly the same: 2 identical dodecagons.

C. Details of the modules

Finally the baseline for the Hcal geometry would be the tilted and optimized configuration illustrated in Figure 6, with 6 rectangles and 6 pseudo-trapezoids, therefore 12 modules.

The module shapes are defined by several parameters, such as the internal radius $\boldsymbol{R_{int}}$ or the calorimeter thickness $\boldsymbol{e_{calo}}$. The different parameters are illustrated in Figure 7, and the corresponding formulas are written below.

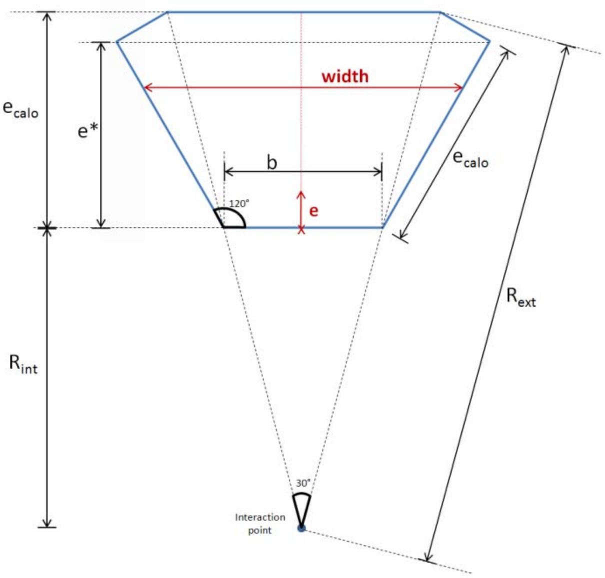

Figure 7: Parameters of the modules

The thickness of the calorimeter depends on the interaction length of the material, the desired interaction length number, the thickness of each absorber layer and the layout of absorbers/chambers. The layout will be discussed later.

Note that the rectangular modules are defined only with the base ***b*** and the thickness $\boldsymbol{e_{calo}}$. The base being one edge of the internal dodecagon, it can be written like this:

$$b = 2 \,.\, R_{int} \,.\tan 15°$$

Moreover, the width of each layer in the pseudo trapezoids, whatever the retained layout, is a function of the Hcal internal radius and the position ***e*** in the thickness of the calorimeter. Thus:

$$e \in [0\,;e_{calo}]$$

Furthermore, the width of the layers increases with the position ***e*** up to a threshold called ***e****, and decreases after. This threshold can easily be written as:

$$e^* = e_{calo} \times \cos 30°$$

Thus, for: $e \in [\,0\,; e^*\,]$:

$$width = 2 \times (\, R_{int}.\tan 15° + e\,.\tan 30°\,)$$

And for: $e \in [\,e^*\,; e_{calo}\,]$:

$$width = 2 \times (\, R_{int}.\tan 15° + 2.\,e_{calo} - e\sqrt{3})$$

Finally, the overall dimension, that is to say the external radius is:

$$R_{ext} = (\, R_{int} + e_{calo}) \div \cos 15°$$

Note that if internal and external belts are used, their thicknesses must be added to the calorimeter thickness in order to obtain the correct external radius.

V. First assembly proposition: stacked design

A. Internal layout

The first proposition consists in a simple stacking of absorbers and chambers. The aim being to obtain a stiff structure in which chambers can be inserted (the latter do not take part in the module stiffness), the idea is to fix stringers, either by welding or thanks to screws, on both sides of absorbers of the rectangles and pseudo-trapezoid modules.

Nevertheless, for trapezoids, stringers have to be machined in order to create a stairs shape, that is to say the complementary shape with respect to the edges of the absorbers. Finally for the last plates, where the tips of trapezoids are cut off, special stringers which will constitute an external belt of the Hcal must have the same shape properties.

Figures 8 and 9 illustrate the two types of modules and for each one: plates, chambers, lateral and external stringers.

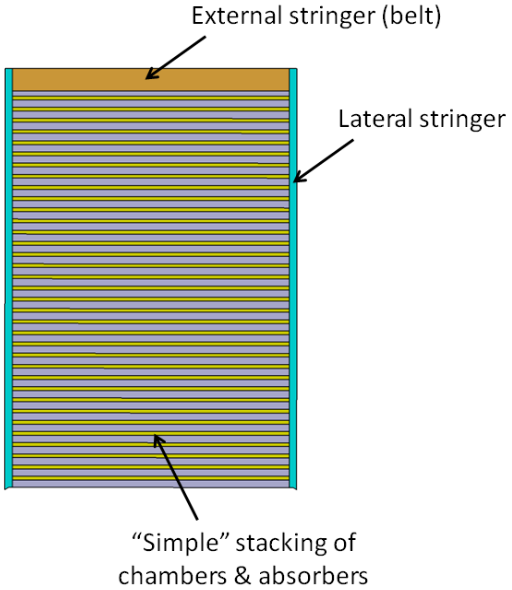

Figure 8: Layout in rectangle module

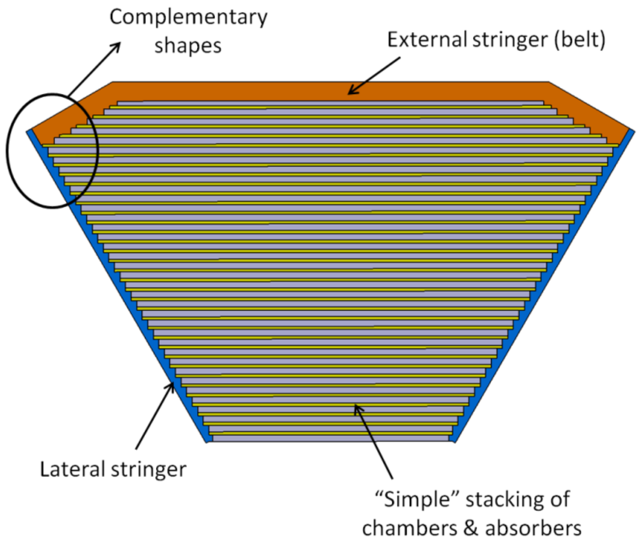

Figure 9: Layout in pseudo-trapezoid module

B. Module assembly

In order to realize the Hcal, the two types of modules must be fixed together. Obviously, the more detection volume there is in the calorimeter, better it is. That is the reason why stringers are not a long plate, whose length is the one of the Hcal, but small parts fixed all along the calorimeter (cf. Figure 10).

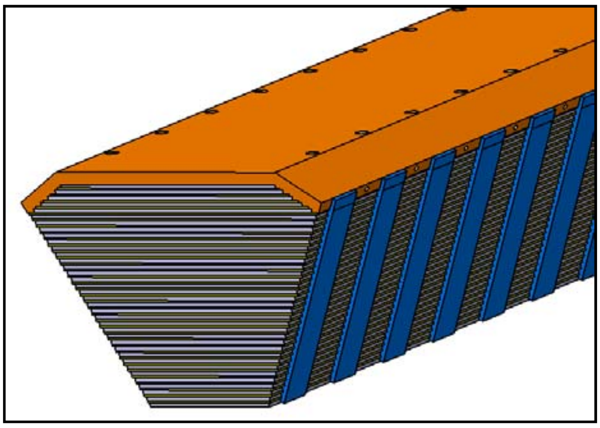

Figure 10: Stringers (in blue) are narrow parts fixed all along the Hcal

Figure 10 illustrates stringers for the pseudo-trapezoids module only; however the same procedure is used for rectangles. Thus, if the stringers of pseudo-trapezoids are shifted with respect to the ones of rectangles modules, stringers of a module can be inserted in the space between stringers of the following module (quincunx assembly).

As a consequence, the space between two consecutive modules is minimized to the thickness of only one stringer and this space is filled with stringers (homogeneous Hcal – no "air gaps"). Figure 11 shows the assembly of several modules.

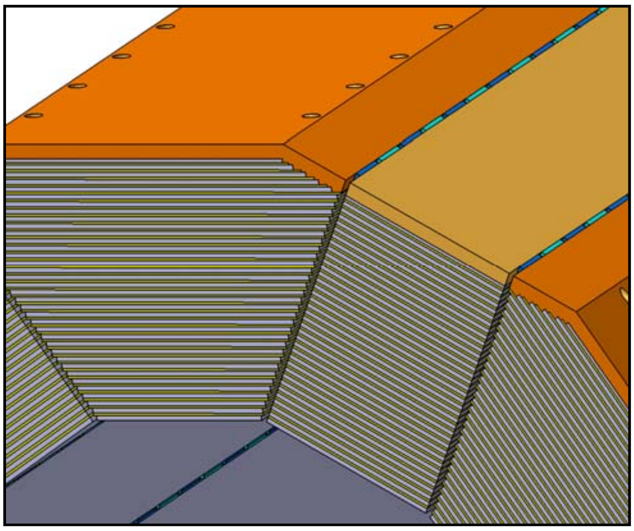

Figure 11: Quincunx assembly for blue and cyan stringers between two kinds of modules.

Moreover in order to fix the twelve modules together, one could use several screws via counterbored holes in the external belt, see Figure 12 and 13.

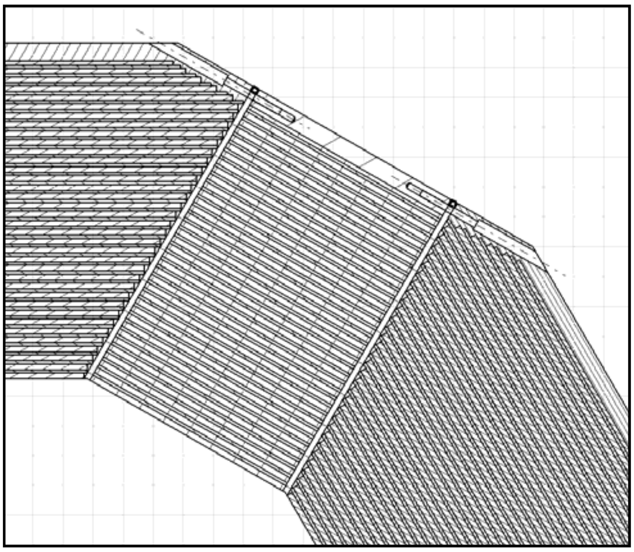

Figure 12: Drawing of the assembly of the modules.

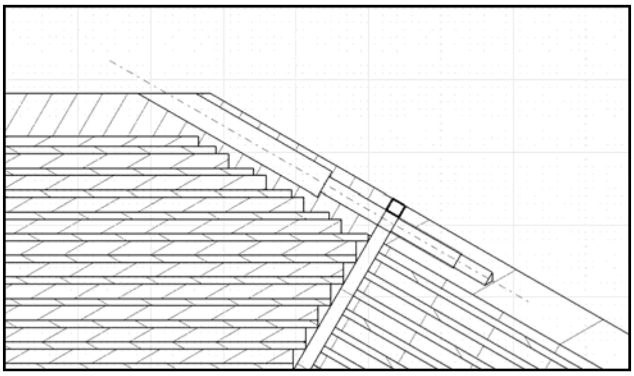

Figure 13: Detailed view of the counterbored hole in belt of pseudo-trapezoid and threaded hole in belt of rectangle module.

These holes could be distributed all along the module (cf. pseudo-trapezoid belt on Figure 11), and this on both sides of the module.

Finally, concerning the fastening device of the internal belt, a 150° bracket and screws can be used, according to Figure 14.

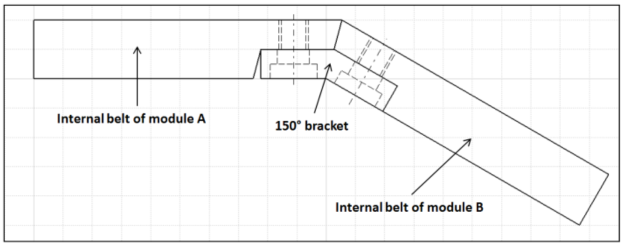

Figure 14: Drawing of the assembly: internal belts with a 150° bracket.

Note that it is also possible to weld the bracket, depending however on the mounting procedure.

During the assembly, module A to be fixed on the previous one (module B) comes in contact (and thus is locked along the radial axis) on the bracket welded on module B. Then screws (or welding) are placed in module A. It is in a sense a relative radial positioning system.

C. Advantages

On one hand, shifted stringers induce the benefit of one stringer thickness, that is to say a gain of space dedicated to chambers!

On the other hand, stringers provide the stiffness of the module, which can be compared to a rigid box, from the bottom to the top. Moreover, the best way to fix the modules together could be to fasten modules in order to create tangential stresses (like a cylinder under pressure). So why not take advantage of the multi-layers sandwich (layers equal to the number of plates) composed by every module? In such a way, the external faces of every stringer would come in contact with the edges of the following module. In addition, screws placed in the counterbored holes of the external belt would probably work mainly along their axis, that is to say essentially in compression (tangential direction for the Hcal).

An internal belt could be designed not only to fix the Ecal wedges on Hcal modules, but also to ensure the radial clamping of each Hcal module with respect to its neighbor (thanks to brackets fixed by screws, the brackets being inserted in the internal belt to save space). Thus, big shearing stresses don't appear, neither in screws placed in the external belt nor in the internal one.

Note that according to the current design described in picture 10, fifteen screws (corresponding to the spaces between stringers) would be used to fasten the modules. These screws would be distributed all along the module, on both sides.

Note as well that the external belt must be optimized in order to have the minimal overall dimension (external radius R_{ext}) of the Hcal. This optimization depends on the size of the screws used to fasten the Hcal, and essentially the diameter of the screw head (i.e. the counterbore).

Nevertheless, the thickness of the external belt could probably be lower than 60mm (dimension used for the design on the different pictures), depending on security factors used for the selection of screw diameter.

D. Drawbacks

The first disadvantage of the assembly comes from the fact that plates can be very large. Indeed, according to the formulas described above, the width can be greater than 1800mm for instance (case of Hcal in stainless steel, with 4.5λ). Consequently deflection of such large plates could become a serious issue…

Moreover is the thickness of the internal belt sufficient to counterbore the bracket?

Finally another drawback (last but not least!) of the stringer is that it creates obviously a volume without detection.

VI. Second assembly proposition: staggered design

A. Internal layout

This second proposition has been developed to overcome the disadvantages of the first proposition, i.e. the deflection issues and the space without detection, dedicated to stringers.

First of all, given there is no more stringer to constitute a module, that is to say to link every absorber plate, the latter must be connected inside the module.

Consequently a continuity of material must be realized from the first plate to the last one. Figure 15 illustrates the second possible internal layout.

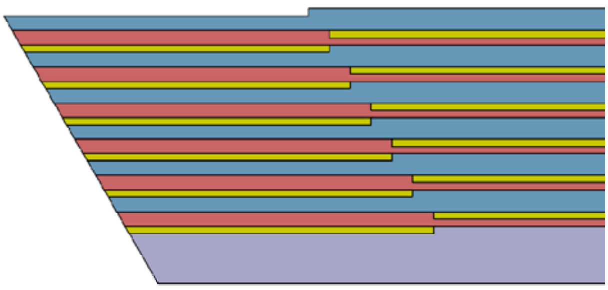

Figure 15: Internal layout of a half pseudo-trapezoidal module:
chambers in yellow, absorbers in red and blue, internal belt in grey.

In order to ensure the continuity of absorbers (which comes from the smaller thickness of the absorbers), discontinuities of chambers appear.

Moreover, if chambers would be at the same radial level, non detective region would be created. On the contrary with shifted chambers, dead spaces are drastically reduced. Finally plates are screwed on the previous one all along the length of the module.

B. Module assembly

This second proposition consists in fixing modules together via flat brackets screwed in the external belt of each module (outer interface region), see Figure 16.

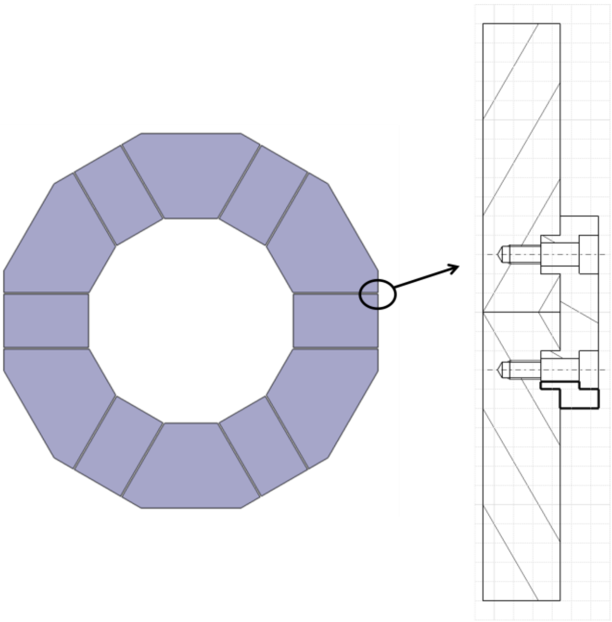

Figure 16: flat bracket and external belts.

C. Advantages

As previously written, this design has been developed to overcome the drawbacks of the first proposition. Consequently, given stringers are no more used, there won't be any dead volume between modules anymore.

Moreover, the boundary conditions of each plate, are no longer at its extremities (case of stringers), but closer with respect to the width of the plate. Thus, the deflection of each plate will be greatly reduced insofar as deflection is a function of the width to the power 4.

D. Drawbacks

The first difficulty is screwing thin plates (approximately 5mm thick), keeping in mind that with this design, the maximal efforts (weight and torques) are concentrated on the first absorber plate (and screws!).

In addition, to realize the plates shown on Figure 15, machining is required (to counterbore chambers). The issue of machining in such thin plates is to be sure to finally obtain straight plates. A solution to this could be to use 5mm thick plates, and to glue them together to constitute the modules with clearance for chambers. Glue thicknesses must however be taken into account.

The issue of deflection must be more precisely checked. Indeed, even if deflection of each plate seems to be decreased (by bringing closer the boundary conditions), the "global" deflection can be increased. Given plates are fixed on the previous ones, the first plate has a given deflection, the second one a bigger deflection, the third one an even bigger deflection, etc... This point has to be checked by FEA, such as the stresses in the thin regions (made for continuity of material).

Note that Figure 15 illustrates the design on a pseudo-trapezoid module. The same design for the rectangle modules seems to be less interesting. Indeed, given that the edges of rectangle modules are parallel, the edges of chambers will be parallel as well (cf. Figure 17).

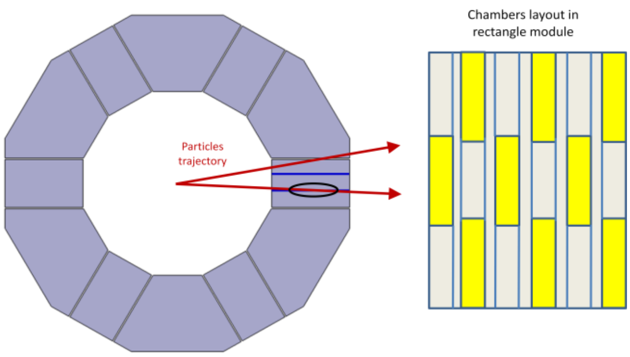

Figure 17: Layout in rectangle modules (first layers only).

There is consequently a tendency to create an internal projective layout (due in a sense to a decrease of tilt). Unfortunately, this tendency is confirmed if, like shown in Figure 18, the external sides of chambers are non detective (due to mechanics for instance).

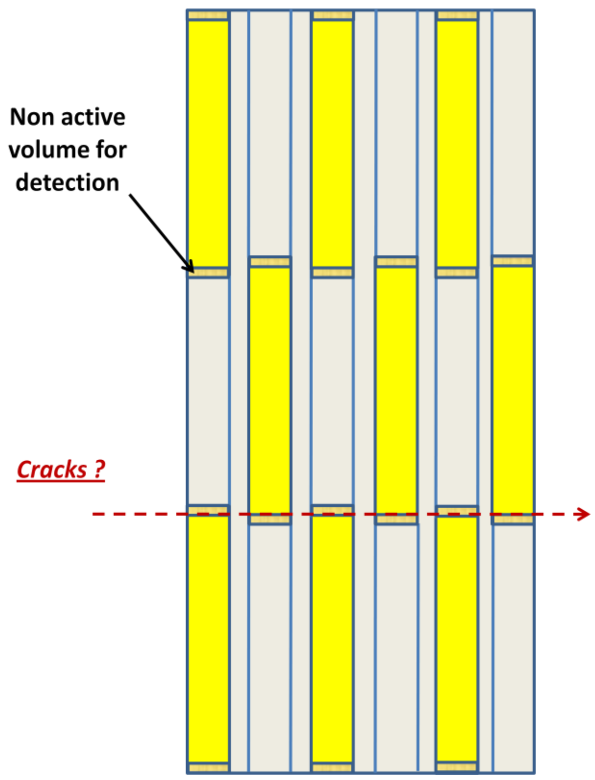

Figure 18: Layout in rectangle.

A solution could be to realize an overlap, big enough to be sure to cancel cracks. Thus stresses will probably increase…to be investigated. However with an overlap, the absorber thickness between two consecutive chambers varies.

The advantage not to have stringers is to fasten modules face to face, and then not to loss space between chambers of consecutive modules. Nevertheless with this design the extremity of each plate can be considered as a cantilever structure, whose parts close to the "clamping" is very thin, then not very stiff. The latter, by getting out of shape (to be verified…) could make a pressure on chambers. Then it would be more delicate to remove chambers, or even worse it could break chambers…

Finally, flat brackets (cf. Figure 16) with two positioning devices, seems to be the best design to fix modules together, not to press them together like screws detailed on Figures 12 and 13.

VII. PROSPECTS

A. Layout & assembly: Hybrid propositions

In order to improve the performances of the Hcal, hybrid designs could be studied.

For instance the second design could be associated with sheet metal playing the role of stringers, whose thickness would be very thin (~2mm), fixed on the "free-fixed structures" to link them in order to increase the stiffness, keep the clearances for chambers unchanged and ensure the contact with the plates of the following module. Note that these "sheet-metal stringers" would be shifted to get only one thickness between modules.

A second possibility could be to realize the first option and to couple it with shifted chambers described by the second design only for the largest plates, i.e. where deflection can be an issue.

Additional work can maybe lead to a third design…

B. Choice of material for absorbers

Two materials seem to be retained: stainless steel and brass (C22000). In order to decrease the Hcal overall dimension, absorbers must be made of the material whose interaction length is the smallest (considering obviously the same number of interaction length for the 2 materials!).

Nevertheless, other aspects have to be taken in consideration, such as the cost, or the Young modulus for instance (the one of brass being half the one of stainless steel).

C. Boundary conditions

Several possibilities are conceivable: either at 3&9 o'clock or at 5&7o'clock for instance. Mechanically speaking it could be more interesting to choose 5&7 o'clock (cf. Figure 19), insofar as for these positions, the efforts are mainly compression loads due to the total weight, whereas for 3&9 o'clock, it creates additional loads such as torques. Consequently, the parts for 3&9 o'clock Hcal fixation would be much bigger than for 5&7 o'clock. Moreover, the bigger the parts for Hcal fixation are, the bigger is the overall dimension!

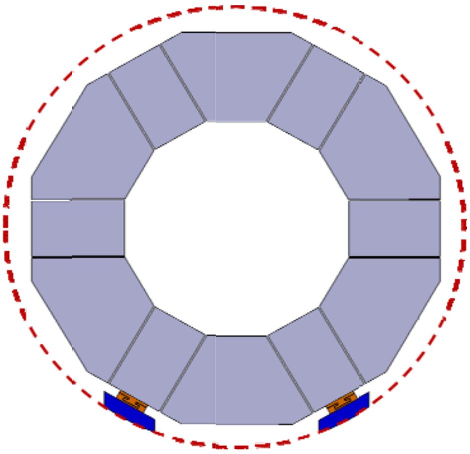

Figure 19: 5&7 o'clock locking devices probably minimize overall dimension

Despite the fact that the 3&9 o'clock positions minimize the Hcal deflection, the latter must be really so stiff that deflection can be neglected.

Thus 5&7 o'clock devices coupled with pushers (springs associated with dampers) at 3&9 o'clock only, playing the role of guide and damping the possible displacements, could be one of the allowable solutions, even in case of an earthquake.

D. Hcal layout along the beam axis direction

A solution could be to build Hcal modules, whose length is the one of the entire Hcal (~5560mm). That is to say not to divide the calorimeter along the Z-direction. Thus it will be probably easier to fix each Ecal wedge (less positioning issues).

Moreover, along Z-direction, two chambers, whose length would be different to avoid projective chambers (not to create cracks inside the modules) could be used. Considering the chambers, this procedure is almost equivalent to have 3 sections along Z-direction (transverse joints "à la" CMS).

Only one chamber would be better but is it realistic?

E. Number of Hcal modules

The designs described above are illustrated with 12 modules: 6 rectangles and 6 trapezoids. However each layout and module assembly can be adapted to a 16 modules division (cf. Figure 20): 8 rectangles and 8 pseudo-trapezoids.

Building smaller modules can be a promising way if stiffer and lighter modules for instance, are required. It could be interesting to study this kind of division for the Hcal, and carry out the study for the Ecal as well.

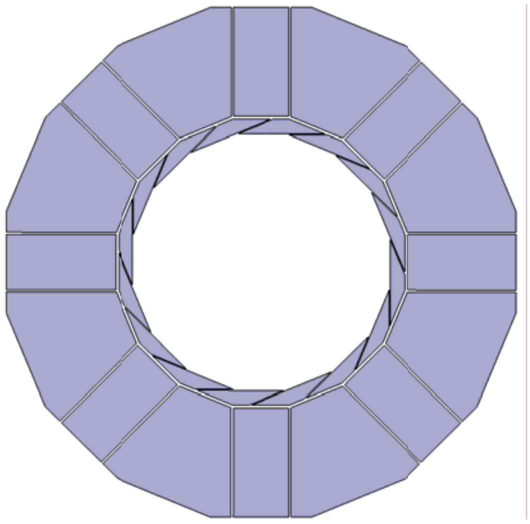

Figure 20: Hcal & Ecal divided into 16 modules

VIII. CONCLUSIONS

The retained shape of the Hcal seems to be the one with 6 rectangles and 6 pseudo-trapezoids. Concerning the internal layout and the assembly, additional studies must be carried out.

Finite Element Analyses are obviously of prime importance to compare the possible solutions. These analyses, linear static, optimization (stringers, belts, screws…) and thermal analysis (heat dissipation) will be realized as soon as possible.

Nevertheless, in order to get satisfactory and univocal results, mechanics simulations (FEA) cannot be achieved without performing physics simulation. Both must be realized in parallel.

At this step, results of physics simulation are crucial to answer unsolved questions…