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# The FCA* layout design

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**Abstract**

A proposal for a possible upgrade around the FCA (the FCA*) based on Thin Gap Gas Chambers has been presented to DELPHI. In this note the detailed design of the FCA* layout is described.

# 1 Introduction

The Technical Proposal for a possible upgrade around the FCA (the FCA*) based on Thin Gap Gas Chambers has been presented to DELPHI and it is described in a separate DELPHI note [1]. In this note the detailed design of the FCA* layout is described.

# 2 FCA geometry

From the references [2, 3, 4] we have the following information.

The FCA trigger strip width is $h = 3.14$ cm. There are 64 trigger strips for each coordinate x, u, v, each rotated by 120° with respect to the others. The external radius of the FCA acceptance is then 32 strips that is $32h = 100.48$ cm. The internal radius of the FCA acceptance is about 9 strips that is about $9h = 28.26$ cm. Starting to count the trigger strips from the center, the strip number $n$ starts at a radial distance from the centre of $3.14 \cdot (n-1)$ cm and ends at $3.14 \cdot (n)$ cm ($n = 1, \ldots 32$).

The actual FCA internal radius is 29.6 cm [5]. The actual FCA external radius is about 103.0 cm [5].

# 3 FCA* geometry

The nominal FCA* position is assumed to be $|z| = 167.0$ cm ([2, 6]). We have then for the FCA and the FCA* the data summarized in table 1.

| Edge | After | Radius | $\theta$ | |
|---|---|---|---|---|
| Inner edge | 9 strips | 28.26 cm | 9.60° | $\sim$ FCA acceptance $\sim$ FCA* inner radius |
| Possible cut (1) | 16 strips | 50.24 cm | 16.74° | Apothem of the middle FCA* hexagon |
| Possible cut (2) | 15 strips | 47.10 cm | 15.75° | Apothem of the middle FCA* hexagon |
| Possible cut (3) | 14 strips | 43.96 cm | 14.75° | Apothem of the middle FCA* hexagon |
| Outer edge (Inscribed circle) | 28 strips | 87.92 cm | 27.77° | $\simeq$ FCA* outer apothem |
| Outer edge (Circumscribed circle) | 32 strips | 100.48 cm | 31.03° | $\simeq$ FCA acceptance $\simeq$ FCA* outer radius |

Table 1: FCA and FCA* geometry.

The TPC first level trigger should work down to about 15° ([3, 7]). Therefore the first two "Possible cut" lines in the table 1 should be able to cover the low angle region not covered by the TPC. The 16 strips option provides a better coverage at low angles (near the TPC edge) but also requires more read-out channels. On the other hand the 15 strips option (as any other odd number option) would destroy the proposed geometry [2, 6, 8] because one would have 15 small equilateral triangles on the side of the hexagon which corresponds to a non integer number (7.5) of big equilateral triangles. The 14 strips option is probably unable to warrant the required overlap with the TPC trigger.

The TPC first level trigger acceptance (according to [3] which is consistent with [4, 7]) is defined by:

$$R_{inf} = 34.5\,\text{cm}; \quad R_{sup} = 111.7\,\text{cm}; \quad |z_{max}| = 134\,\text{cm}.$$

The TPC first level trigger acceptance lower $\theta$ limit, extrapolated to the nominal FCA* position, gives:

$$R_{no-TPC} = 43.0\,\text{cm}.$$

### 3.1 Ideal geometry

Ideal geometry refers to the ideal part of the FCA* without taking into account the geometrical acceptance loss due to the construction of the real detector. Following reference [6] the ideal FCA* geometry is assumed to be that of two hexagons with parallel sides and the same center, built of six 60° modules each one of trapezoidal shape. The real geometry and actual detector acceptance will be considered later.

Following the references [2, 6] the inner and outer edges defined in table 1 (respectively 9 strips and 28 strips) are used and the "Possible cut" at 16 strips is used. In this way one finds the ideal FCA* geometry in figure 1 (from [8]).

In terms of the FCA geometry the ideal FCA* geometry of one module is plotted in figure 2 ($h$ = 31.4 mm, $l = 2h/\sqrt{3}$ = 36.2576 mm, $L = 2l$ = 72.5152 mm) and in figure 3. Note that, using an integer number of FCA strips, if we cut at 28 strips we do not find an hexagon exactly inscribed in the circumference of radius 100.48 cm (i.e. the external radius of the FCA acceptance). This would require cutting at 27.7 (i.e. $32\sqrt{3}/2$) strips. Cutting at 28 gives the closest integer number and gives a radius of the FCA* equal to 101.5213 cm. In this way the maximum radius of the FCA* is slightly bigger than the FCA acceptance but it is anyway inside the physical dimensions of FCA (see the paragraphs 2 and 3.2).

### 3.2 Real detector

The ideal geometry discussed above is assumed. Compared to the ideal geometry it is necessary to modify the inner edge ($R_{ie}$ = 28.26 cm) to the minimum allowed to be compatible with DELPHI, $R_{int}$ = 29.6 cm, corresponding to the minimum radius of the FCA [5]. On the other hand the outer edge ($R_{oe}$ = 100.48 cm) can be increased to about $R_{ext}$ = 103.0 cm corresponding to the maximum radius of the FCA [5].

According to the actual estimates the space left between the major basis of the trapezium and the circle of radius $R_{ext}$ = 103.0 cm is enough for the placement of the electronics.

To pass from the ideal geometry to the physical dimensions of a 60° module 1 mm has been cut from the two radial sides. In this way the clearance between two nearby modules is 2 mm.

At the major basis a small rectangular strip is taken out the trapezium described above to place the pads for the connectors (this is described in paragraph 4.4).

This produces the dimensions in figure 4.

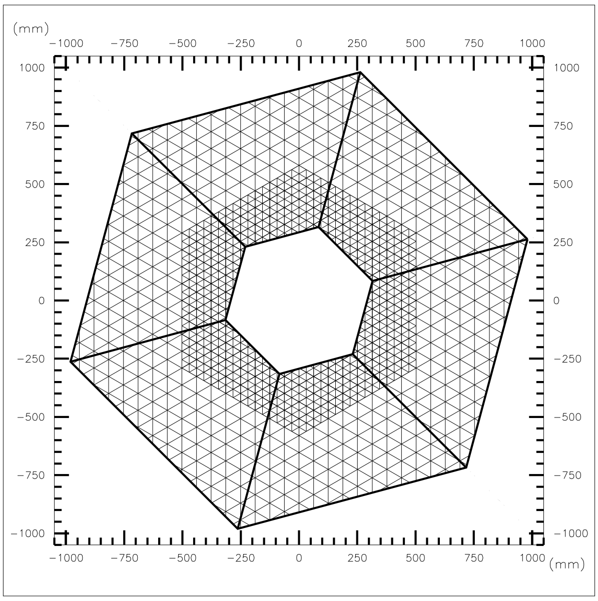
### 3.3 Detector acceptance

To estimate the detector acceptance (which is necessary at this stage to decide which pads and strips must be read-out) the following data have been assumed.

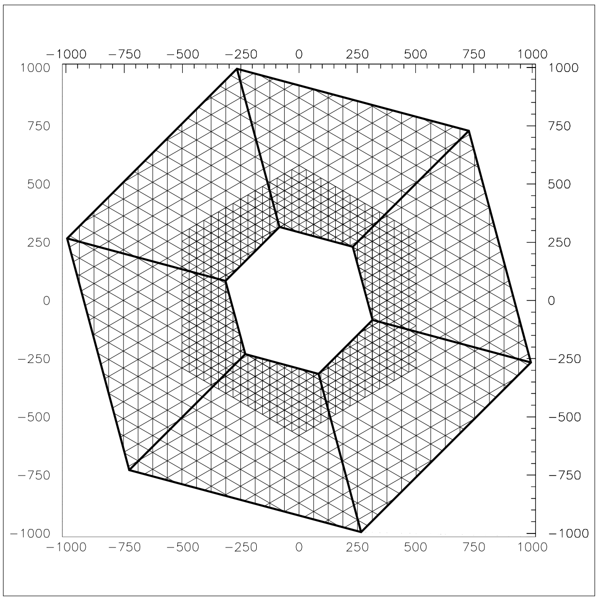
One might expect to lose about 2.5 cm in the acceptance at the two radial sides.

One might expect to lose about 1.0 cm at the inner edge. The inner radius of the acceptance then becomes 30.6 cm, corresponding to a lower $\theta$ angle of 10.4°. The lower limit of the full $\theta$ acceptance turns out to be 11.5°. With two staggered planes of chambers the lower limit of the $\theta$ acceptance (with at least one plane) turns out to be the average value of the two numbers above, that is 11.0° which is exactly the lower limit of the FCA acceptance. Above 11.5° there is full coverage with two planes.

One might expect to lose about 1.5 cm at the outer edge. This is largely dependent, among other things, on the space required by the electronics, HV and gas systems. The full acceptance




(a) The first cathode trigger layer




(b) The second cathode trigger layer

Figure 1: Layouts of the two trigger cathode planes. The two planes are flipped, respect to each other, around the vertical axis.

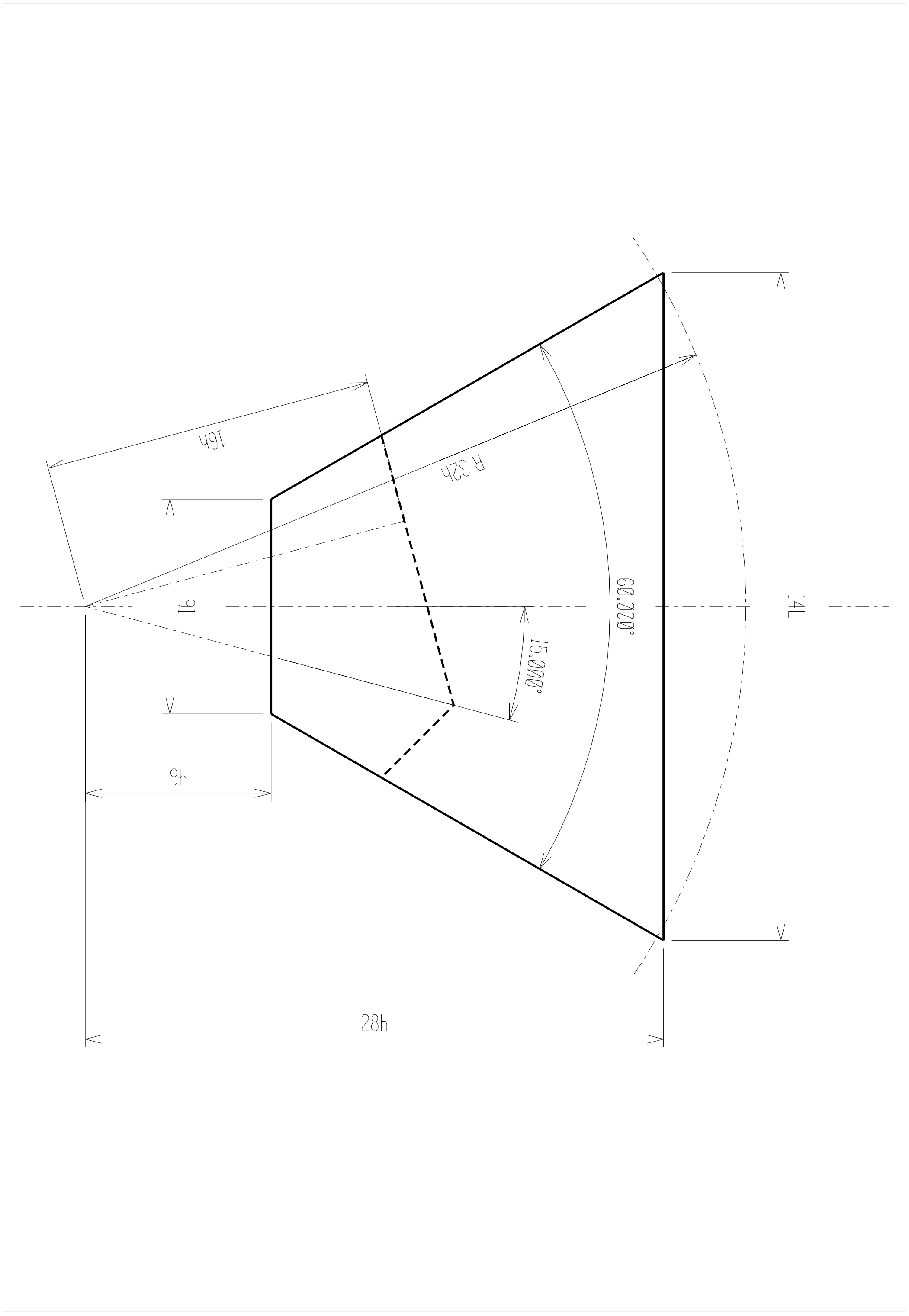



Figure 2: Ideal geometry in terms of the FCA geometry parameters.

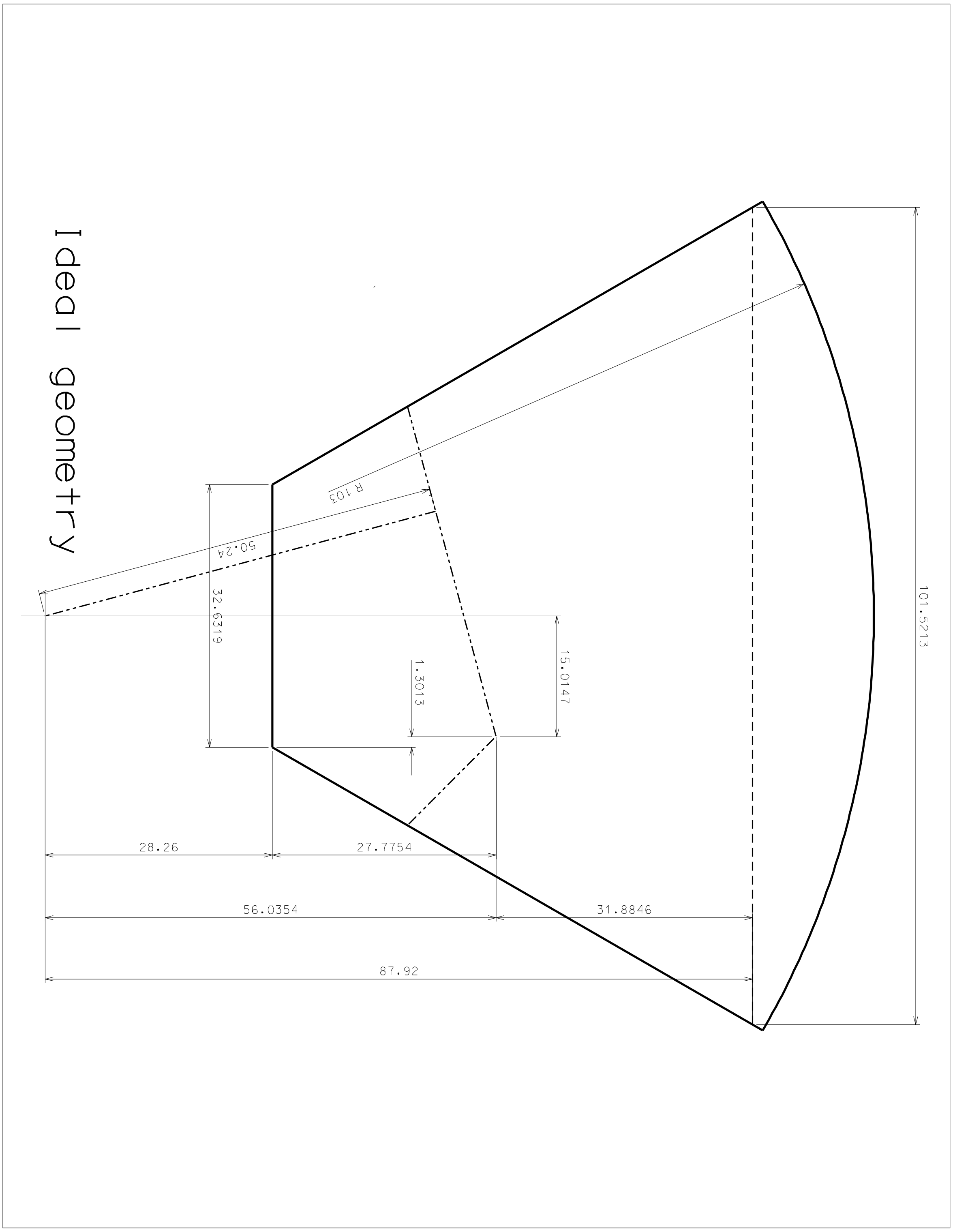



Figure 3: Ideal geometry (dimensions in cm).

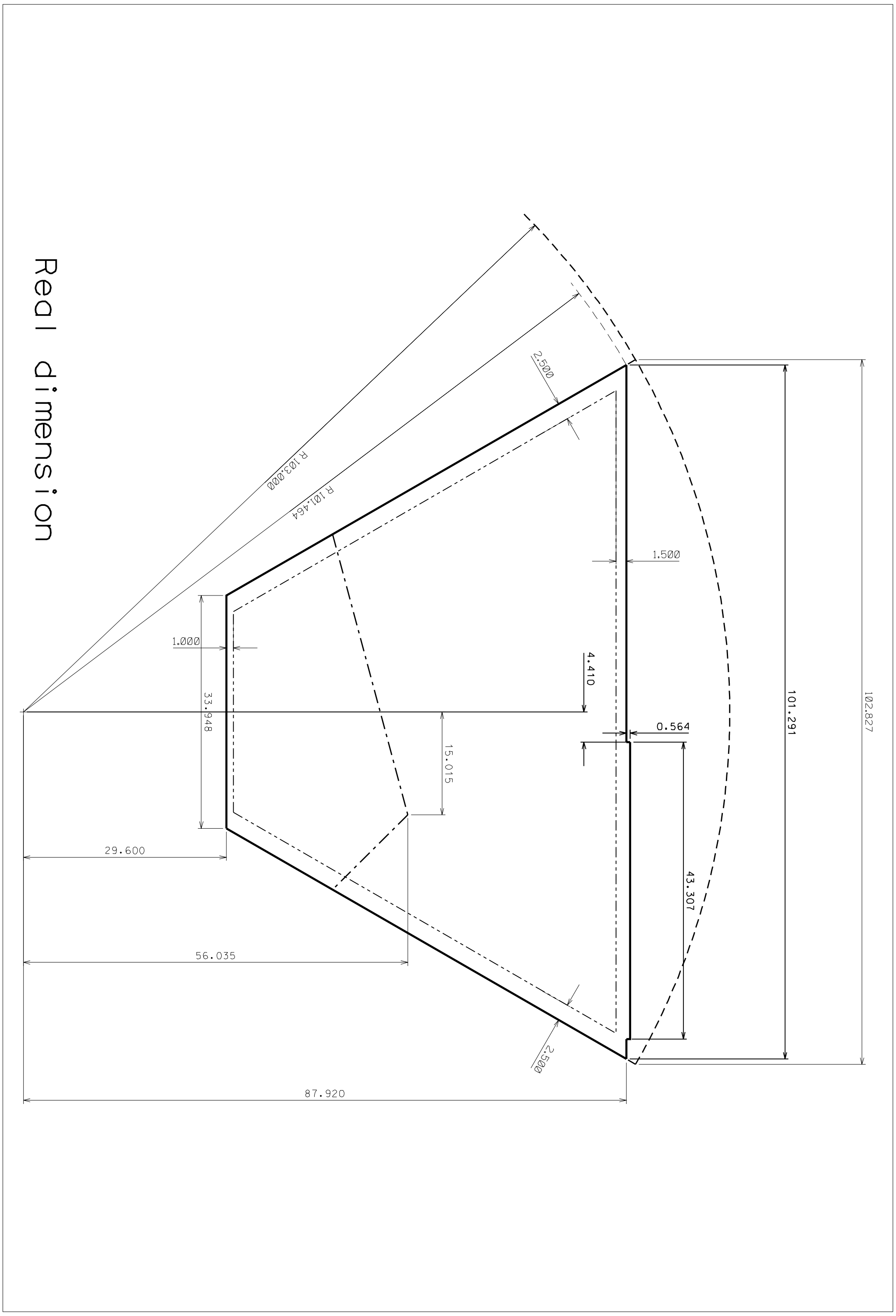



Figure 4: Real geometry (dimensions in cm).

(with both planes) at the outer edge then corresponds to a maximum $\theta$ angle of 27.36°. The acceptance at the outer edge with at least one plane corresponds to a maximum $\theta$ angle of 28.94°. This is somewhat less than the FCA acceptance but at such polar angles the TPC is fully efficient.

With these assumptions the acceptance is the inner (dot-dashed) trapezium in figure 4.

### 3.4 Space for the electronics, HV and gas systems

Assuming the dimensions defined in paragraph 3.2 an upper limit to the surface available for the placement of the electronics, HV and gas systems or anything else is $\approx 1000$ cm$^2$ (see figure 4).

## 4 FCA* pad structure

### 4.1 Triangular pads

The ideal length of the sides of the equilateral triangular pads are $l = 36.2576$ mm and $L = 2l = 72.5152$ mm respectively for big and small triangles. Both dimensions come from the FCA trigger strip width $h = 31.4$ mm. The real dimensions of the equilateral triangular pads are slightly modified (decreased) by the spacing between two nearby triangular pads which has been set to 0.5 mm.

To decide which triangles must be read-out the assumed detector acceptance (see paragraph 3.3 and figure 4) is used. The triangles along the border are read-out if the fraction of area lying inside the assumed detector acceptance is larger than 0.3 for the big triangles and larger than 0.5 for the small triangles. This produces a number of read-out channels which is possible to handle with the actual electronic scheme.

With this choice we have

- 223 full triangles of which:
  - 88 big triangles,
  - 135 small triangles;
- 50 cut triangles of which:
  - 34 big triangles,
  - 16 small triangles;
- Total number of channels: 273.

The resulting pad layout is plotted in figure 5. In figure 6 the conventional numbering scheme for the triangular pads which are read-out is displayed. Note that in both figures the contour of the assumed detector acceptance (see paragraph 3.3), which is used to determine which pads must be read-out, is not drawn (compare with figure 4).

The cut triangles along the border which are not read-out are connected to ground.

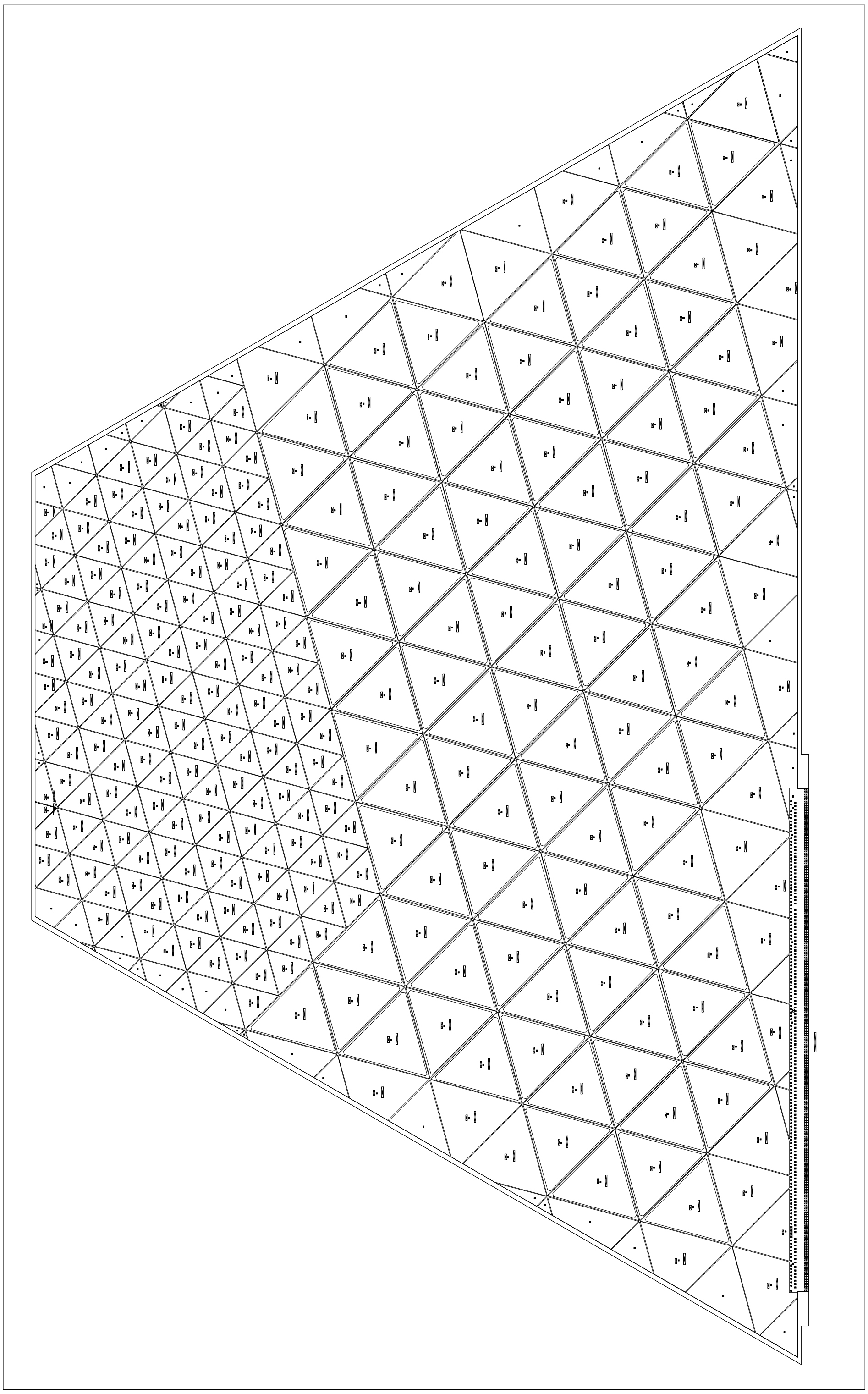


Figure 5: Triangular pads layout.

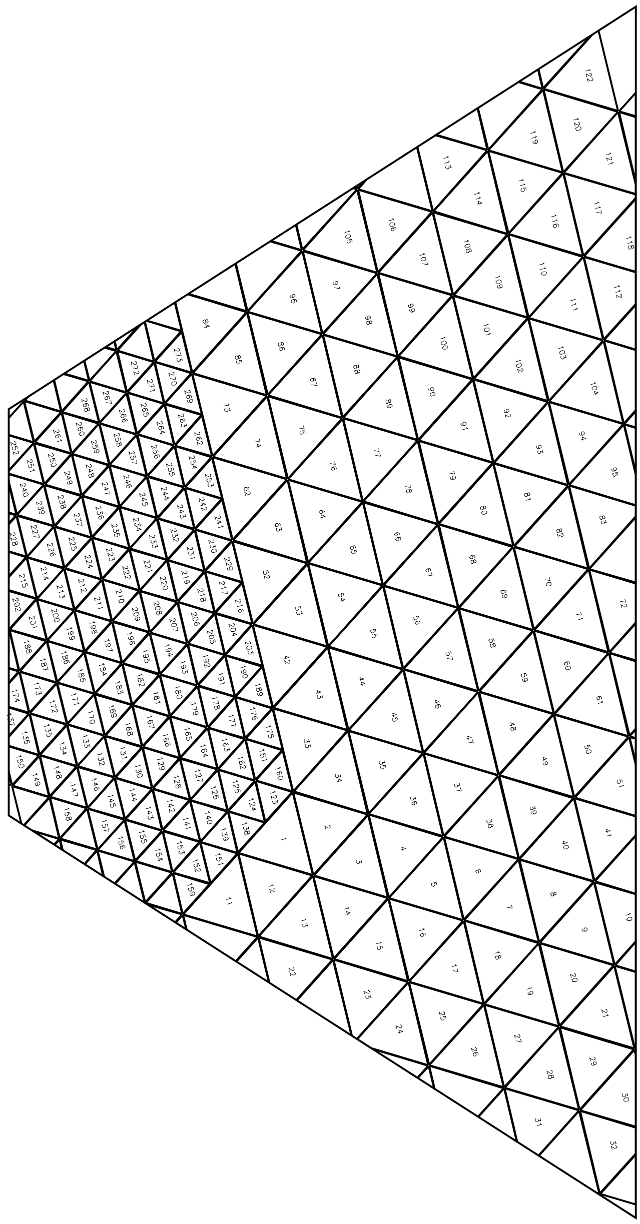


Figure 6: Conventional numbering scheme of the triangular pads.

### 4.2 Radial strips

The number of radial strips has been fixed to be about 260, corresponding to a number of channels which can be handled by the electronics. They have been designed pointing to the center so that every strip defines a $\phi$ angle. Besides it would be nice if the angular segmentation would fit an integer number of times in 30°. In this way, if additional planes with radial strips should be installed with a 30° relative rotation, the radial strips of the different planes would coincide in $\phi$. The angular step has been then assumed to be $\Delta\phi = 0.2174°$. In this way 262 strips are enough to cover the geometrical acceptance region. At the two radial edges four more strips are available for read-out, two per side, in case it will be possible to reduce the dead region on the two radial sides of the module. The total number of strips is then 266. Two extreme strips, which will be grounded, have been designed to match the trapezoidal shape of the module. The spacing between two strips has been set to the constant value of 0.3 mm. Note that this spacing is smaller than the one used for the triangular pads because the radial strips are very narrow close to the minor basis of the trapezium.

With this design the two central strips have a width ranging from 0.8 mm (at the minor basis) to 3.0 mm (at the major basis). The extreme strips have a width ranging from 0.9 mm (at the minor basis) to 3.5 mm (at the major basis).

With this arrangement of strips the maximum loss in the geometrical acceptance at the two radial sides, if one reads all 266 strips, is 1.7 cm at the maximum polar angle covered by the detector, i.e. at the major basis of the trapezium. This is well below the 2.5 cm assumed in paragraph 3.3. The full $\phi$ acceptance of the radial strips is $\Delta\phi = 57.8°$.

A plot of the radial strips layout is shown in figure 7.

### 4.3 Transverse strips

The transverse strips consists of 266 strips running parallel to the two basis of the trapezium with a constant pitch of 0.22 cm that is $\delta\theta \simeq 0.07°$.

To avoid having strips parallel to the basis of the trapezium (i.e. parallel to the wires of the chamber) one might consider to rotate the overall pattern of transverse strips by 30° in azimuth obtaining strips having the same direction of the $(x, u, v)$ coordinates (see figure 1).

### 4.4 Connectors

A row of pads for the connection to the electronics has been placed along the major basis, outside the trapezoidal shape defining the real geometry (see figure 4). The row of pads occupies 38.2 cm along the major basis, starting at 5.3 cm from the vertex of the trapezium and ending at 6.9 cm from the axis of the trapezium. The depth of the rectangular region, lying outside the real geometry and carrying the row of pads, is 5.6 mm. At the two sides of the pad array a free region of 2.54 cm has been left. The row is composed of 300 rectangular pads with 1.27 mm (50/1000 of an inch) spacing. The two faces of the chamber, one with the triangular pads and the other with the radial strips, have their row of pads for the connectors located symmetrically about the axis of the trapezium (when the detector is assembled).

In the case of the radial strips the length of the connection has been made uniform among the different strips. In figure 8 different possible solutions are shown. The solution corresponding to a length of 19.5 inches (very close to the minimum allowed) has been used to maximize the strip width at the location where the hole and pad have to be placed. The exact solution shown in

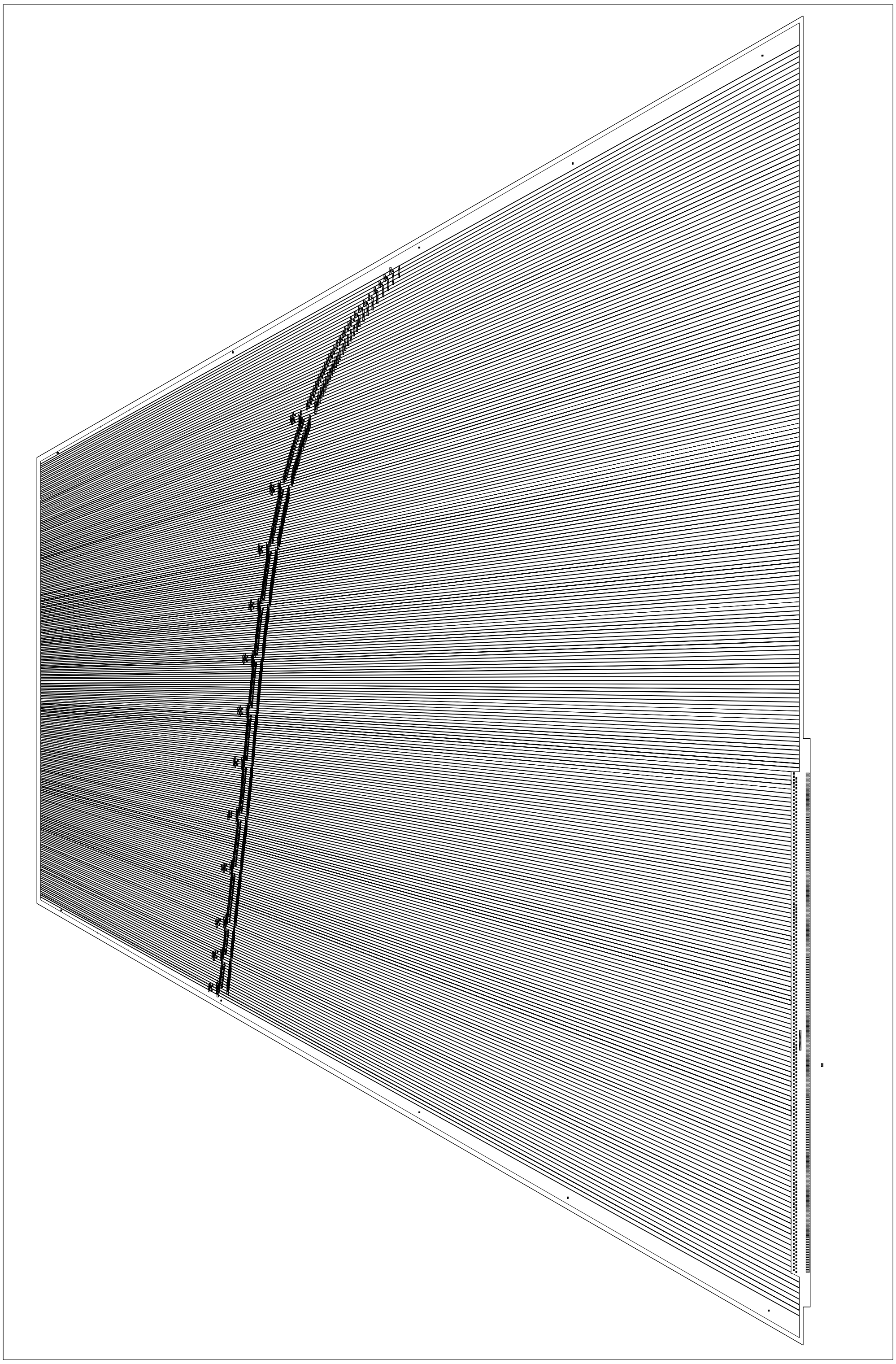


Figure 7: Radial strips layout.

figure 8 has been approximated by a few line segments. The starting point of a few connections have been slightly moved from the determined solution (by less than 1 cm) to avoid having a long cut in the third layer ground plane (see paragraph 5).

# 5 PCB design

## 5.1 PCB structure

The PCB consists of five layers. A schematic cross section of the PCB structure is drawn in figure 9. The first layer is fully isolating except for a grounded copper strip, running all around the trapezoidal shape, starting at 2 mm distance from the PCB border and ending at 10 mm distance. This first layer covers the second layer with the pad/strip structure described in paragraph 4. The third layer is a ground plane. The fourth layer has the electrical connections from the pads/strips to the row of pads for the connectors. The width of the copper traces is 0.3 mm. The minimum allowed distance between any two copper traces is 0.254 mm. The connection between the pads/strips in the second layer and the fourth layer is done by a 0.5 mm diameter plated trough via hole. In correspondence of each via hole the third layer (ground plane) has an isolating region. The fifth layer is a shielding copper layer. The grounded pads/strips, the third layer ground plane, the fifth layer shielding plane and the grounded strip in the first layer are all connected together by via holes all around the trapezium contour. The first layer has to be put in front of the second (pad/strip) layer and covered with graphite. The grounded copper strip along the border (outside the detector acceptance) is introduced to ensure proper electrical grounding of the graphite.

The second and third layers are the two sides of a 1 mm thick FR4 board. The fourth and fifth layers are built on two one-sided 0.1 mm thick FR4 boards and glued. The first layer is a 0.2 mm thick FR4 board (like in [10]) glued on the pads/strips plane and covered with graphite. The thickness of this board has possibly to be optimized together with the surface resistance of the graphite. Taking into account the copper thickness the total thickness of the PCB turns out to be 1.61 mm.

## 5.2 PCB (Computer Aided) Design

The (Computer Aided) Design of the PCB has been carried out according to what described in the previous paragraphs. All dimensions of the PCB (Computer Aided) Design conform to those described here to better than 0.2 mm (in most cases much better). Differences are mainly due to the finite resolution of the CAD system, rounding errors and unidirectional accumulation of small errors in the multiple replicas which are necessary to draw the pad and strip structure.

## 5.3 Fiducial marks

To facilitate the assembly of the two PCBs forming the chamber a set of fiducial marks has been drawn on the fifth copper layer of each PCB (i.e. on the outer side of the chamber). In this way they will be visible while assembling the chamber allowing the relative alignment of the two PCBs. They will be also visible when the complete detector will be installed in DELPHI giving the opportunity to measure precisely the position of the detector.

The following set of fiducial marks (a redundant set) has been used. One mark at the origin of the local reference frame which is the vertex of the intermediate hexagon which defines the border

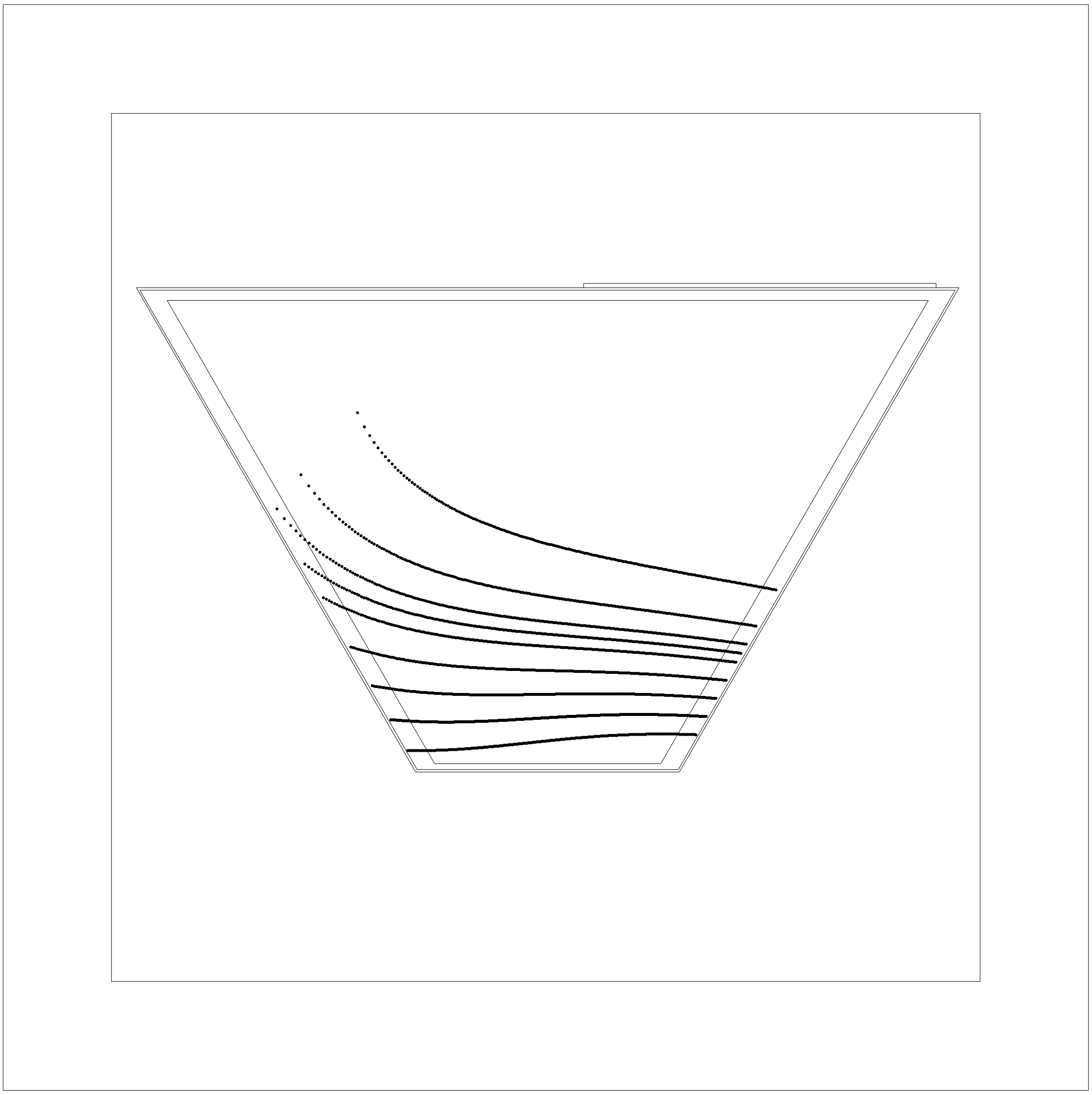


Figure 8: Possible equal length connections of the radial strips.

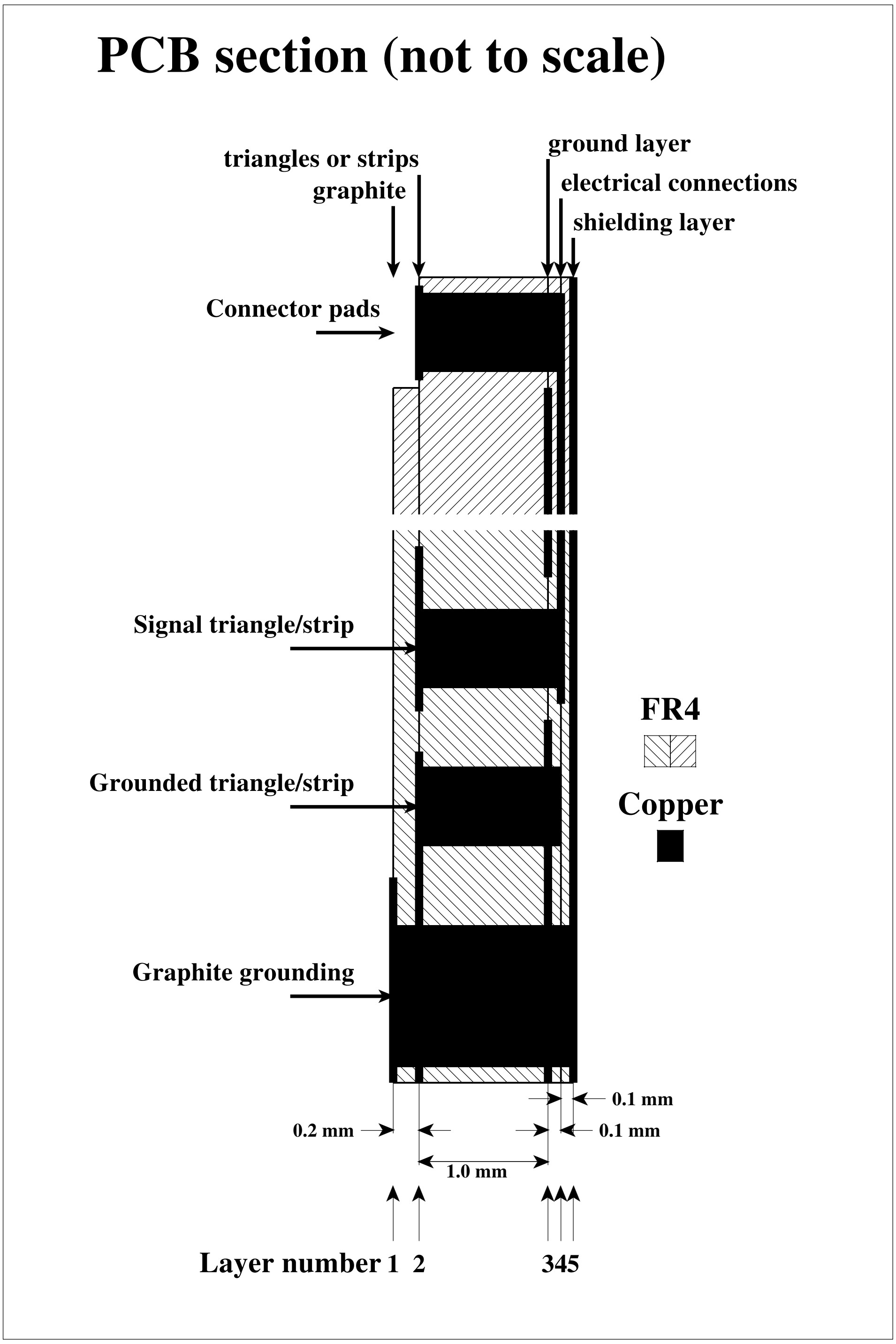



Figure 9: Section of the PCB structure. The thickness of the PCB layers doesn't take into account the thickness of the copper layer.

between the small and big triangles regions. All positions of all objects in the PCB are accurately known relative to this point from CAD. A set of marks all along the trapezium perimeter, placed at about 3 cm from the physical border of the PCB, whose position are accurately known relative to the origin (from CAD). One mark has been placed in correspondence of each vertex and four additional marks at the middle of each side.

The precision of the position of the marks in the local coordinate frame is essentially limited by the precision with which the PCB can be built.

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