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Canonical SCT-Modules for Physics Simulations

The Semiconductor Tracker Group

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1 Introduction

This document describes the suggested and implemented geometry of the silicon strip detector modules of the SCT detector for physics simulations using DICE and ATRECON. The subdetectors of the SCT are:

- 1 layer of Silicon Pixel Detectors at a radius of 4 cm or optionally Silicon Strip Detectors at 6 cm radius to be used as a vertex detector. (described in a separate document)
- 2 layers of Silicon Pixel Detectors at radii of 11.5 and 16.5 cm. (described in a separate document)
- 4 layers of Silicon Strip Detectors at radii of 30, 40, 50 and 60 cm. (described in this document)
- 4 Silicon Pixel Wheels at 49.92, 55.40, 79.90, and 85.00 cm (described in a separate document)
- 2 GaAs wheels at z=155.7 and z=182.5 cm. (described in a separate document)

The suggested geometry for the SCT-Silicon-Strip-Detector is not a full engeneering design, but provides a realistic description of:

- Material as a function of eta, $X_0(\eta)$
- Material as a function of phi, $X_0(\phi)$
- Manufacturable detector sizes
- Dead areas
- Overlaps between modules
- Arrangement of the detectors in the $u(v)$ layers

2 Noise and Inefficiencies

A realistic implementation of noise and inefficiencies from all sources will be very important for the predictive power of the simulations. We therefore suggest the following implementation scheme:

- To obtain globally reproducible noise levels, noise should be simulated which includes genuine noise hits but also channels not firing due to downward signal fluctuations of all subdetectors in the SCT.
- The parameters of the noise tapes to be generated should be determined by the performance of all SCT-electronics designs under consideration.
- The noise tapes should be added to the generated hit banks in the same way as background events.

3 The Silicon Strip Module

The module described in this section can be used without modification to cover barrel layers with radii between 30 and 60 cm.
It is tuned to cover barrels of 160 cm length in z. The suggested modules described in this paragraph, differs slightly from the actually implemented version described in section 5.

3.1 Global Parameters

- The module uses back to back single sided strip detectors of 300 μm thickness each.
- The arrangement of the strips is alternating between u-phi and V-phi starting with a u-phi layer at 60 cm.[1]
- The stereo angle is 40 mrad.
- A $u(v)$ measurement uses the same detectors as a phi measurement, with the detectors rotated around the centre of the Module by the stereo angle.
- The module intrinsic resolution at all radii is:
  $\sigma_{r\phi} = \sigma_U = \sigma_V = 20\,\mu m$.
  This has to be added in quadrature with the alignment errors of:
  $\sigma_{align,r\phi} = \sigma_{align,U} = 10\,\mu m$.
- The strip pitch in the simulation representing the combined resolution is then given by :
  $P_{r\phi} = P_U = P_V = 75\,\mu m$.

[1] A u strip shall be defined to be created by turning the vector of the magnetic field by the stereo angle in the mathematically positive (anti clockwise) direction when viewed from the vertex

3.2 Technological/Engineering Parameters

- Each detector will have an inactive edge of 1.2 mm. This represents a cutting edge of 0.5 mm and 0.7 mm for a multi-guard structure.

- There will be no overlap between the two detectors constituting a module. This will lead to a dead area in the centre of the module of 2.4 mm width corresponding to a geometrical inefficiency of apr. 2 % per module. This dead area is however very dependent on the technology used to manufacture and cut the detector and can consequently vary by large factors.
  There is a strong opinion inside the SCT community that this dead area will influence the performance of the tracker and therefore should be implemented in a way, that allows modification after an event has been simulated. We suggest that this should be done by applying a mask during the digitization step, respecting the geometrical shape and orientation of the dead area.

- The overlaps between modules will be used to align the modules relative to each other, whereas the alignment inside a module is supposed to be implemented at construction time with an accuracy exceeding the expected resolutions by a large factor.

- Modules will overlap each other in z by 3.0 mm, representing an 0.6 mm overlap of the active areas as seen from the beam pipe. This corresponds to an extra silicon area of apr. 3 % per module. The overlap can be seen in figure 1.

- To achieve this z-overlap, consecutive modules in z have to be radially separated by Δ_R. Where

  $$\Delta_R > 2 * D_{silicon} + D_{clearance} = 0.6 + 0.1mm$$

  A value of $\Delta_R = 1.0mm$ has been chosen.

- Modules should overlap each other in $r\phi$ by at least 3.0 mm, representing 8 or more active strips at normal incidence for a straight track. This corresponds to an extra silicon area and increase in all related components (electronics, cooling, interconnectivity etc.) of 2.38 %

- The total length of a module should be such that the barrel length[2] of 160 cm is made of an even integer number of modules, taking into account the overlaps in z. This leads to a module length of 11.71 cm for 14 modules along the length of the barrel.

- The total width of the module is determined by the maximum size that can be cut from a 4 inch wafer. It is W_{mod} =6 cm.

[2]The length of individual barrels is subject to optimization of the transition region between forward and barrel detectors. It has to be agreed within the inner detector community.

- The tilt angle of the modules with respect to a tangent to a cylinder at the nominal radii (30, 40, 50 or 60 cm) in the centre of the module should be as small as possible to have optimal usage of the active silicon area. For engineering reasons the tilt angle should not be smaller than 5 degrees.[3]
- The centre (in $r\phi$) of the active area of each module will be on its corresponding nominal radius. This fact plus the constraint to cover the circumference with an minimum integer number of modules also limits the range of the tilt angle β_{tilt}.

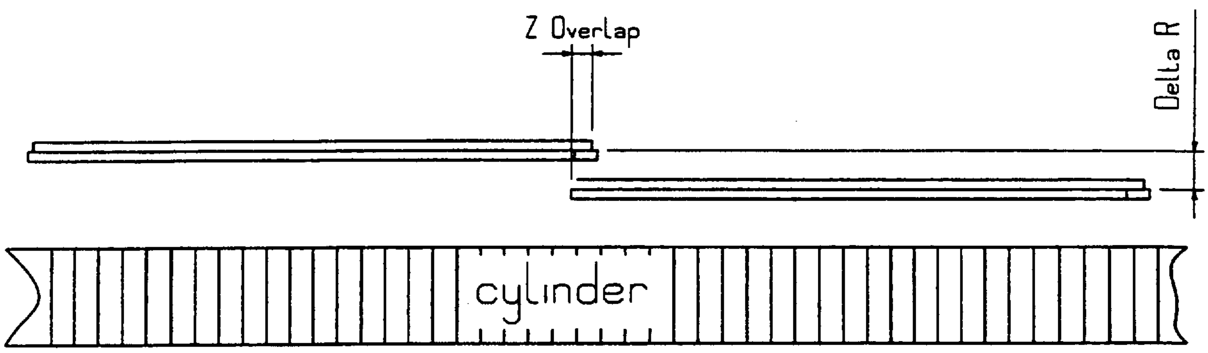

Figure 1: r-Z-projection of two modules overlapping in z, showing the overlap region and the radial separation. $\Delta_R = 1mm$ is not represented to scale in this drawing.

A summary of the module dimensions derived in the previous two sections can be seen in table 1

L_{cryst}	W_{cryst}	D_{cryst}	L_{board}	W_{board}	D_{board}	L_{dead}	X_{dead}	α_{stereo}	Δ_R
117.1	60	0.30	110	25.0	0.30	2.40	1.20	40 mrad	1.0

Table 1: Dimensions of the SCT silicon strip modules in mm. The meaning of the various dimensions can be seen in figure 3. X_{dead} indicates the width of the dead edge of the detector. D_{board} can be varied to give the radiation length described in section 3.4 with any material

3.3 Simplified Volume Model

Two views of a module are shown in figures 2 and 3.

3.4 Radiation Length Breakdown

The radiation length in this section are given for normal incident particles and are normalised to the active area served by one module, including the overlap regions between modules.

[3]In a fully engineered SCT the tilt angle will be optimised to give the best resolution due to the Lorentz angle effect, maintaining ease of assembly and access.

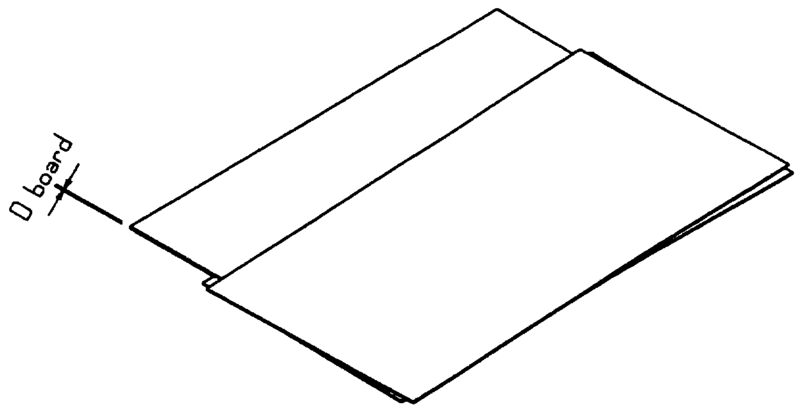

Figure 2: Perspective drawing of a volume model for a silicon strip module.

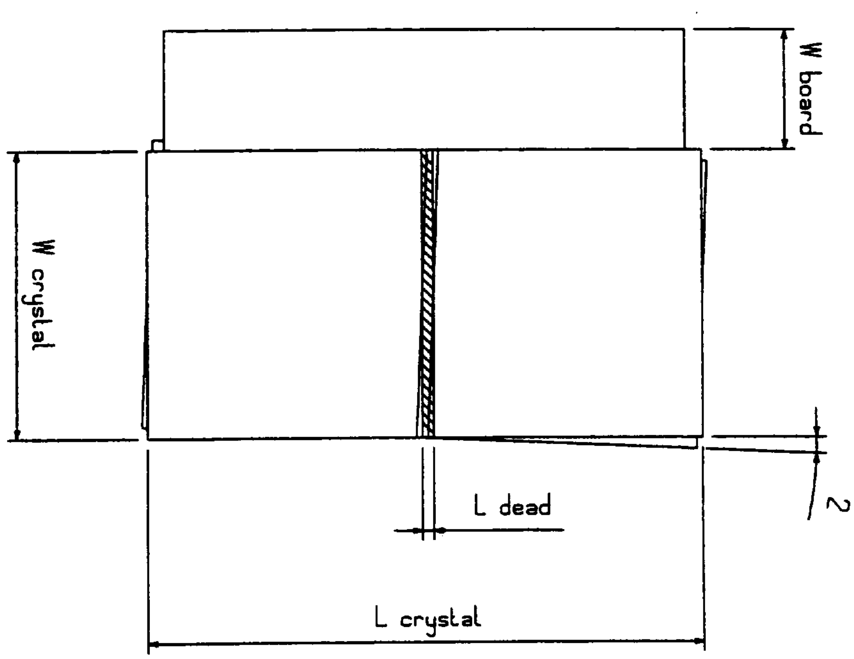

Figure 3: $r\phi - Z$-projection of a silicon strip module. The dimensions are derived in sections 3.2 and 3.1 and summarised in table 1

The numbers given in brackets are those normalised to the total projected area of a module. This will lead to identical numbers for those components described as full cylinders. The numbers in brackets are hoped to be more convenient for the implementation in DICE.

Since the total active overlap is apr. 3 %, the radiation length of any layer homogeneously spread around a cylinder, will be apr. 1.03 times larger than the total radiation length per module given here.
It is understood that the item 'Support Cylinder' in the following list represents all components that are homogeneously spread around the cylinder.
The block of material underneath the silicon was introduced to implement the inhomogeneity of the material in phi.
The material for each item was chosen arbitrarily and does not represent any bias to a particular module or support design.

- Support cylinder (carbon): 0.15 % (0.15 %)
- 2 Silicon detectors, each 300 μm thick: 2*0.32 % = 0.64 % (0.69 %)
- Readout Board (50 % fibre glass, 50 % copper) (incl. chips, discrete components, solder,etc.): 0.46 % (0.5 %).
- All remaining materials except for the power cables are summarised as a block (named 'lumped' in figure 4) under the silicon detector: 0.28 % (0.3 %)
- The total radiation length per module is 1.53 (1.64)% X_o
- In addition to this each module will be equipped with a power cable of 0.022 (0.024) % X_0 building up along z to $7 * 0.022$ %=0.154 %. Each cable starts at the centre (in z) of its module and continues to the end of the barrel at z=160 cm.

4 Tiling of Silicon Strip Modules

The tiling of the modules around a cylinder is shown in figures 4 and 5 and has been obtained using a 3D-volume model in a EUKLID CAD system. Table 2 shows the parameters obtained for the different radii with this model. The abbreviations in the table are explained by figure 4. To realistically implement a tiling model the minimal dimensions of the 'lumped' material in figure 4 had to be known. They have been chosen as:

$$\Delta_R(lumped) = 6mm \text{ and}$$
$$\Delta_{r\phi}(lumped) = 10mm.$$

It has to be noted that specifying the tilt angle β_{tilt}, the number of modules around a cylinder and the nominal radius of the centre of the silicon detectors already fully determines a tiling.
Specifying also the overlap between modules in $r\phi$-direction O_{phi} and the various radii of figure 4 overdetermines the tiling and one set of uniquely defining variables has to be chosen for implementation.

As opposed to what is shown in figure 4, the lumped material should not be mounted on the module but rather on the cylinder surface. The 8 mm difference between R_{lumped} and $R_{cylinder}$ is then made up by $\frac{\Delta_R(lumped)}{2} + D_{cylinder}$.

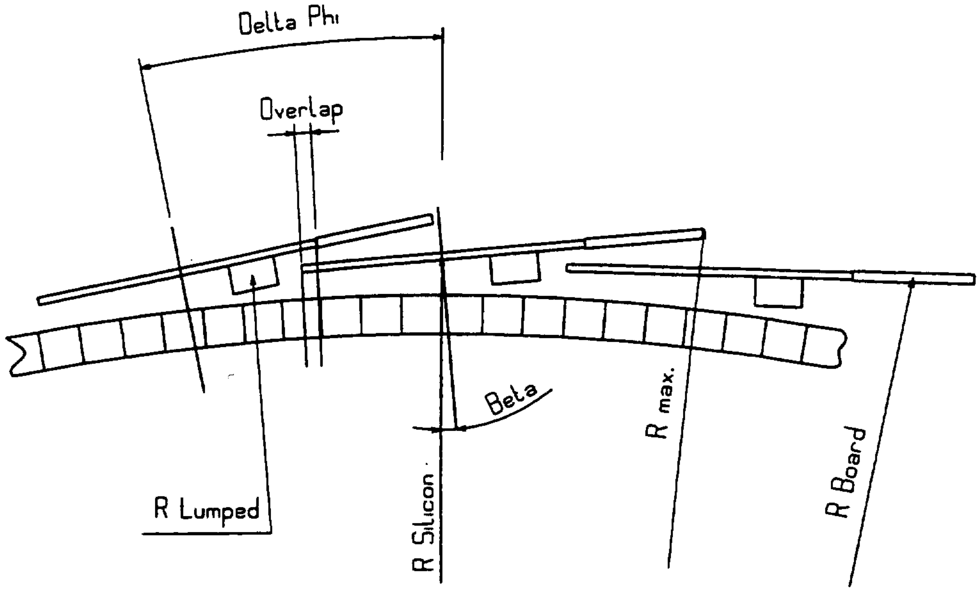

Figure 4: $r\phi - r$ view of a layer with the various radii indicated.

$R_{silicon}$	$N_{modules}$	R_{max}	$R_{cylinder}$	R_{lumped}	R_{board}	$O_{r\phi}$	β_{tilt}	Δ_{phi}
300.0	34	310.9	287.0	295.0	307.4	0.716°	6.0°	10.59°
400.0	45	408.8	387.0	395.0	405.9	0.540°	5.0°	8.0°
500.0	56	508.1	487.0	495.0	505.5	0.409°	5.0°	6.43°
600.0	68	607.6	587.0	595.0	605.2	0.406°	5.0°	5.29°

Table 2: Parameters of SCT silicon strip layers. All radii are with respect to the geometrical centers. $R_{silicon}$ refers to the centre of the outer detector. R_{lumped} is always 8 mm larger than $R_{cylinder}$ as explained in the text. For explanation see figure 4. All dimensions are in mm unless explicitly given.

5 Geometry implementation of the SCT in DICE.

This section outlines which of the specifications given above for the SCT have been included in the DICE simulation package.
The main features of the SCT described above have now been incorporated into DICE, these include:

- Rotation of modules to obtain stereo angle.
- module overlap along the z-axis as well as phi overlap.

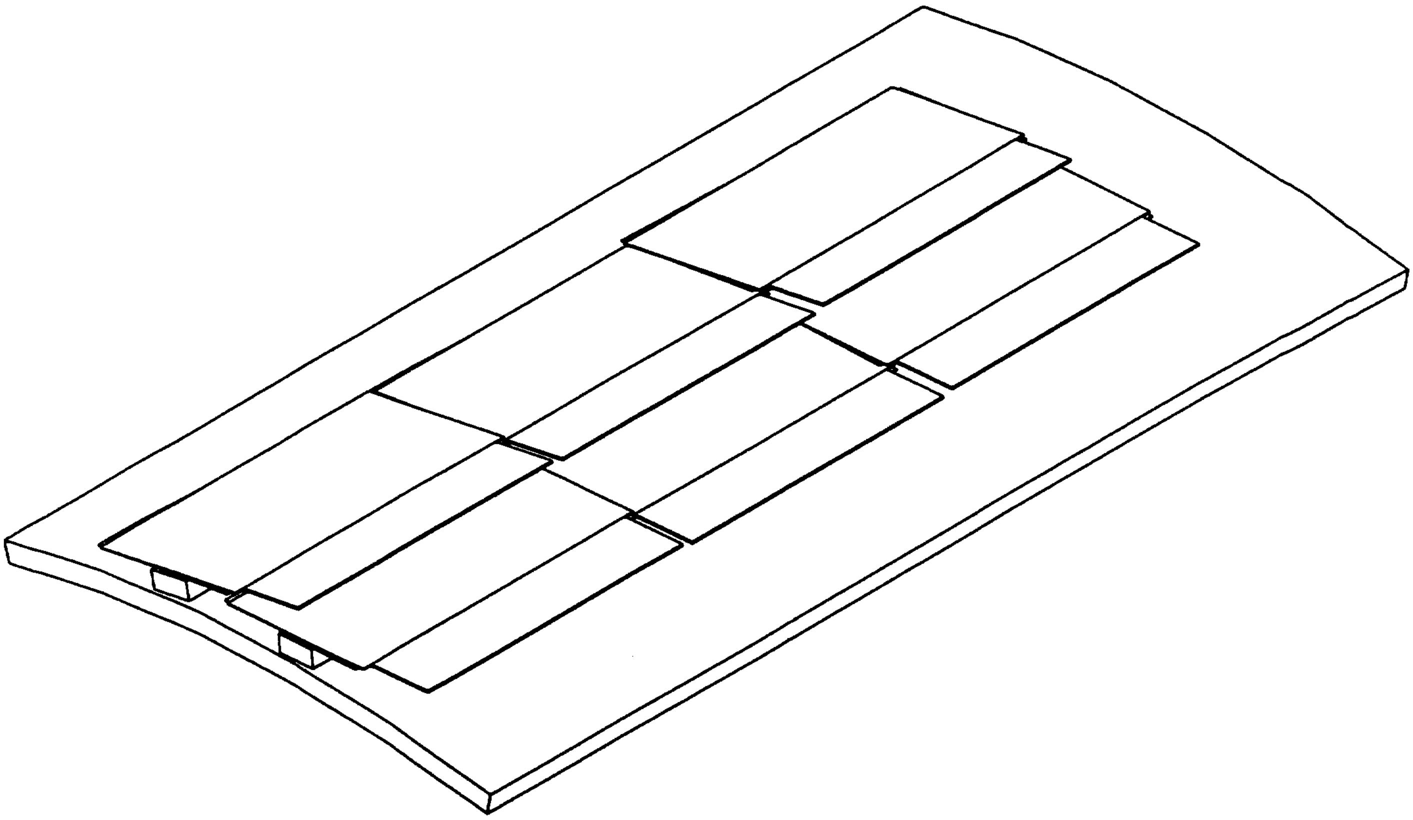

Figure 5: 3D-view of a 2*3 module wide section of a tiled layer, showing the alternating radial positions of modules along z and the overlap arrangement in $r\phi$-direction.

- Dead area implementation.
- Lumped material.
- power cable.

A crossection through one layer of the SCT, drawn by GEANT can be seen in figure 7. Further more an isometric view without hidden line removal to show the internal structure of the modules is shown in fugure 6. Here every second row of modules has been removed to make the drawing more understandable.

Note that in the case of the stereo angle, the implementation in DICE was done such that the user can choose stereo strips where the modules are rotated by the stereo angle or to have crossed strips (done in the digitisation step) without rotating the modules. The different default[4] parameters used are now described in tables 3,4 and 5.

The services of the silicon layers were divided into two parts. The support structure and the cables and cooling. the support structure was taken to be a constant 0.5% X_0, and the cables and cooling pipes were taken to be 0.44% X_0. The cables and pipes decrease in thickness as they go out in radius. These were implemented as rings of different thicknesses.

A picture of a tapered ring used to represent the services at the end of the barrel is given in figure 8. The global arrangement of the service disks is shown i figure 9.

[4]All default parameters can be controlled from datacards.

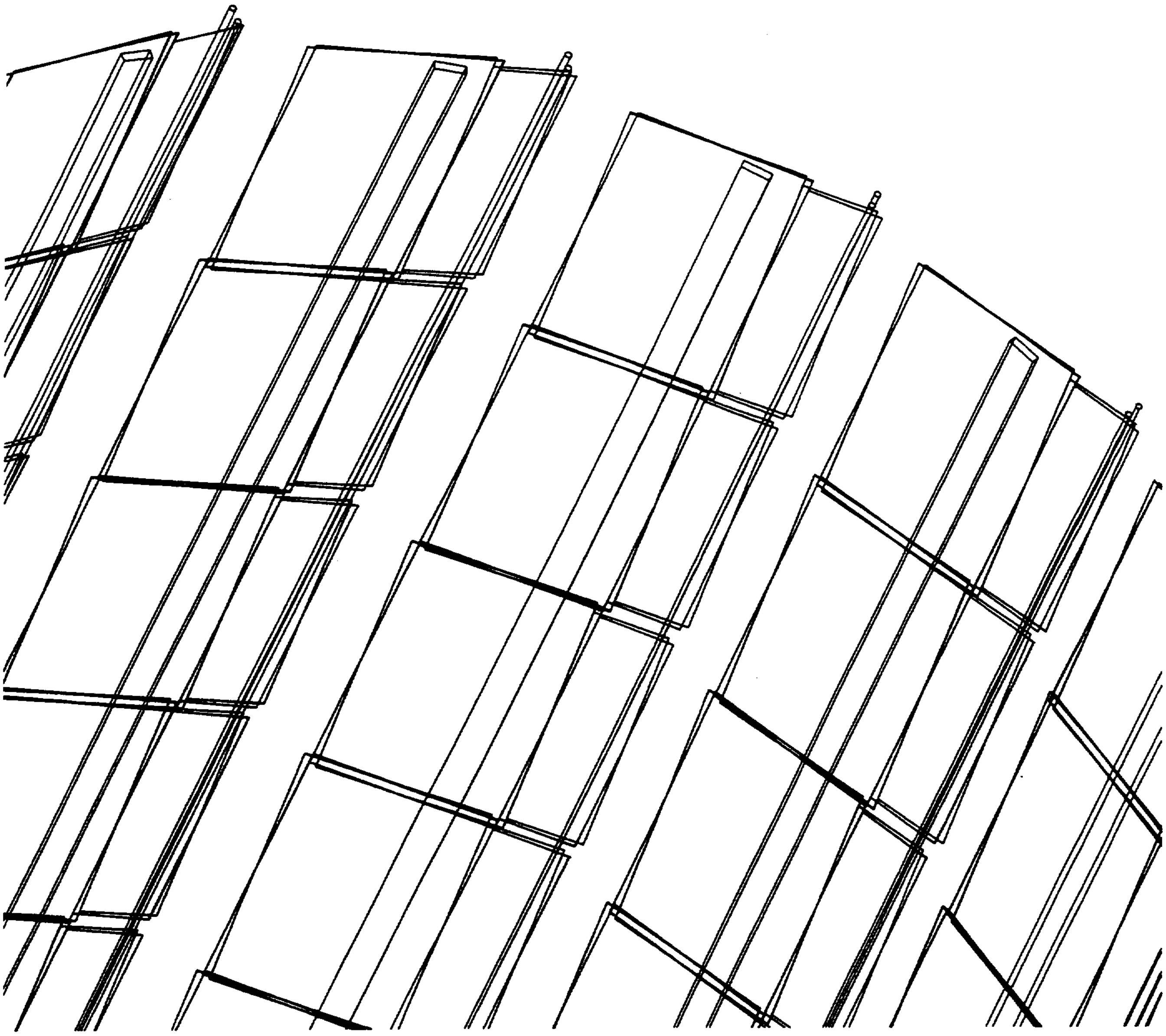

Figure 6: Isometric view of one layer of SCT modules as drawn by GEANT. For simplicity every second row of modules has been removed from the drawing. The internal structure shows the two rotated submodules on top of each other. Their rotation gives the correct stereo angle for the lower side submodule. The cooling pipe and electronic board of each submodule and the lumped material can be also be clearly seen

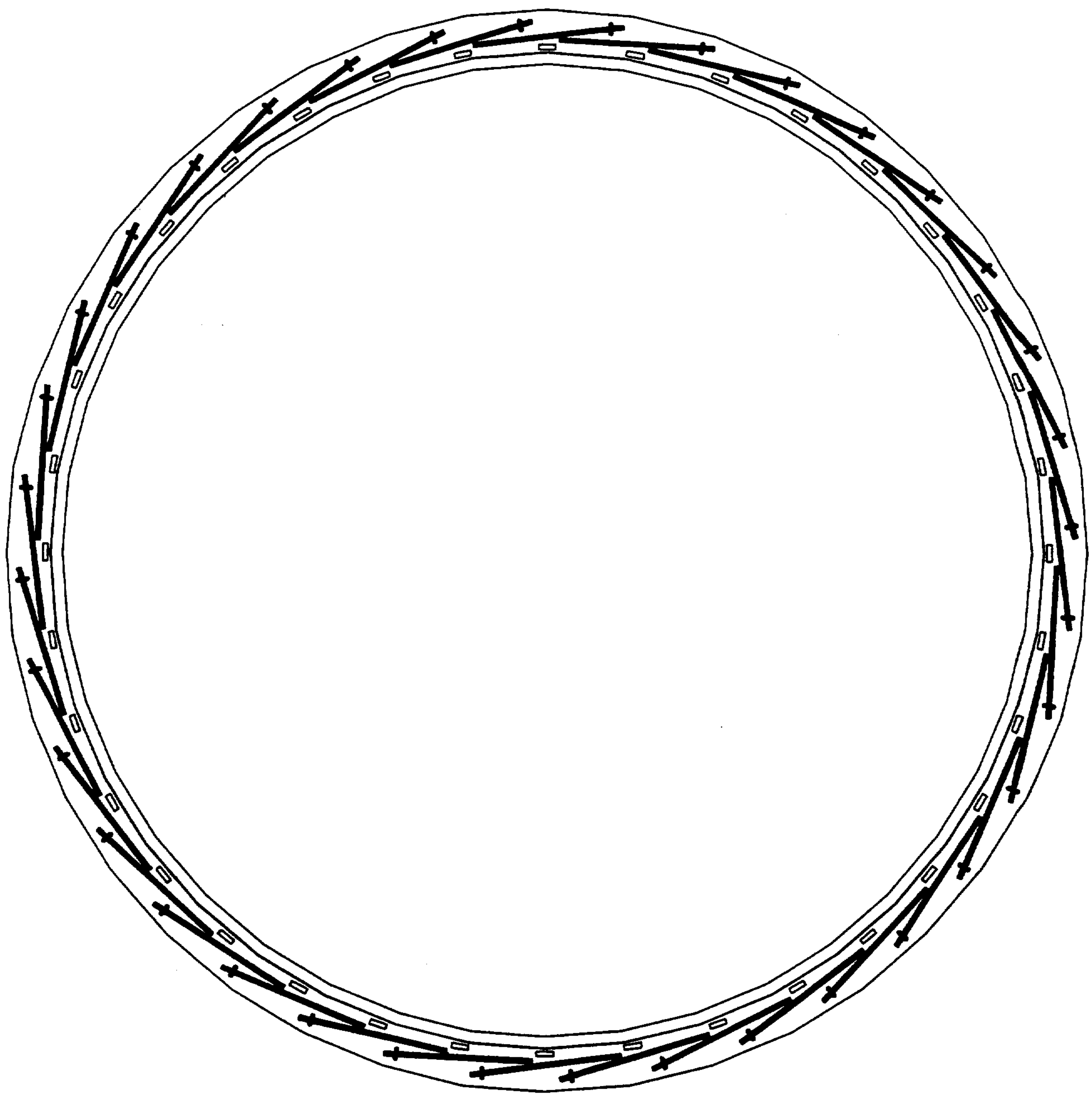

Figure 7: View of a layer of SCT-Detectors as drawn by GEANT. The symmetry of the modules around their centers reflects the fact, that two identical half modules have been put on top of each other with the correct rotation angle to create stereo strips on one side. The two cooling pipes of each module can also be seen.

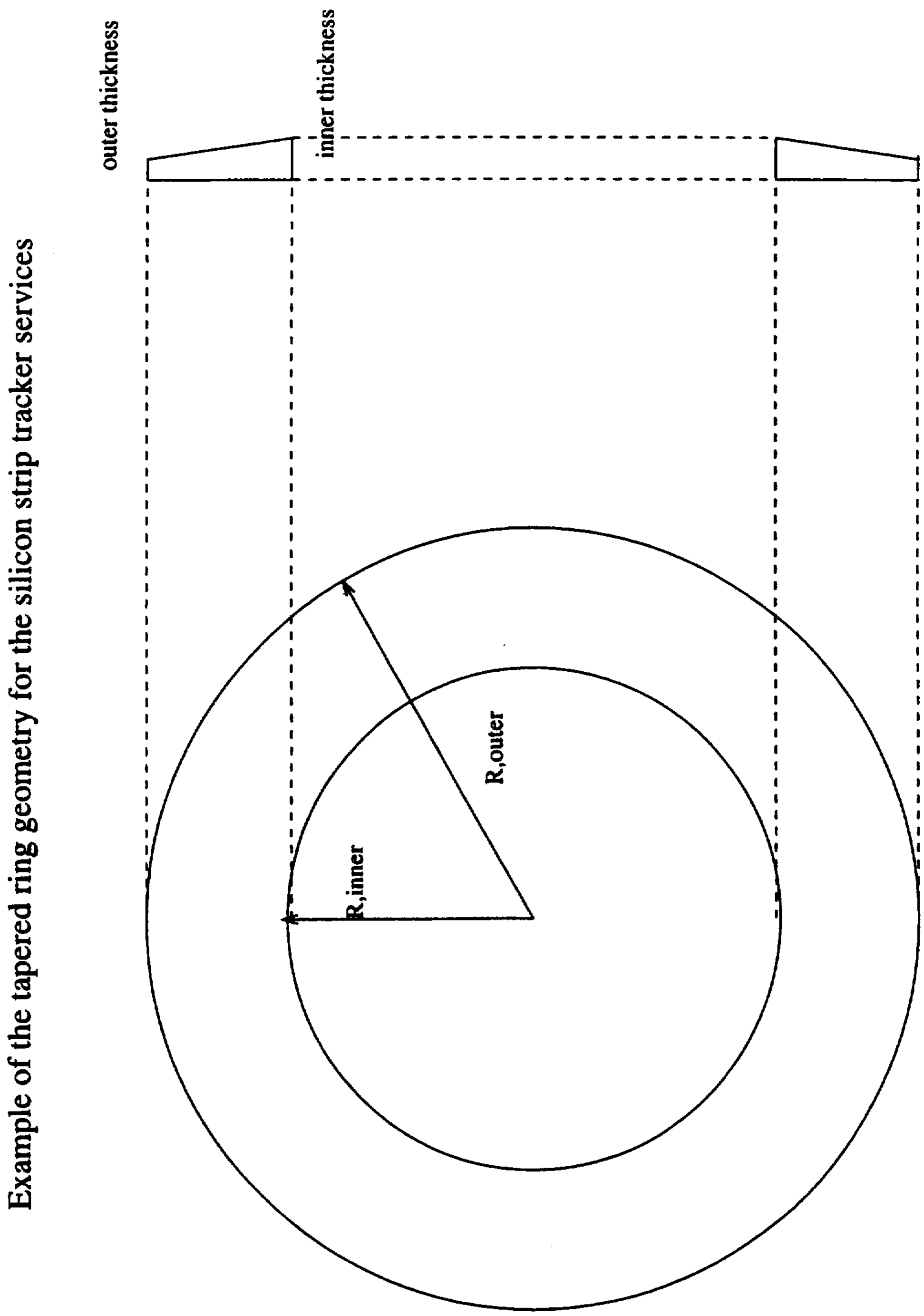

Figure 8: A schematic drawing of one tapered cylinders used to represent the services of the SCT as they leave the barrel section

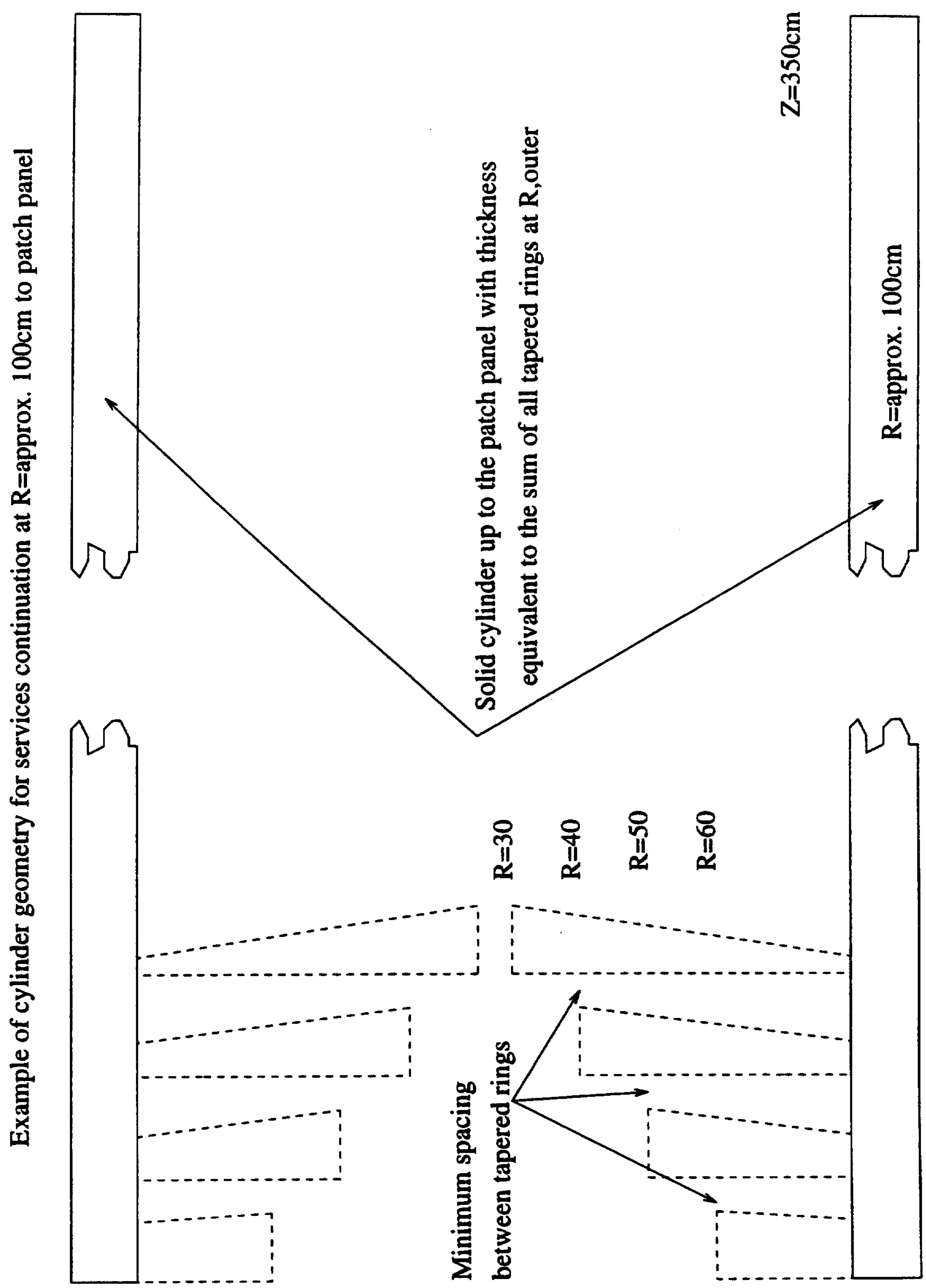

Figure 9: Arrangement of the services of all SCT barrel layers going out from the barrels. The drawing is schematic and not to scale

Layer number	Radius (cm)	Tilt angle
1	30.0	7^o
2	40.0	6^o
3	50.0	5^o
4	60.0	5^o

Table 3: Phi tilt angles of the modules in the different modules chosen to eliminate volume overlapping in GEANT.

L_{cryst}	W_{cryst}	D_{cryst}	L_{board}	W_{board}	D_{board}
120	60	0.3	110	25.0	calculated from rad. length

Table 4: module dimensions.

It should be noted that a module consists of one 12x6 cm^2 detector, an electronics board and a cable. Two modules were placed on top of each other, with a seperation of 100 microns to simulate the module described earlier in the note. This was done for easier implementation into DICE.

Component	Material	Radiation length[5]% X_0	Radiation length used in DICE
Active detector	Silicon	0.32	unchanged
Electronics board	Carbon	0.5	0.6
Power cable	Copper	see footnote[6]	see footnote
Lumped services	Carbon	0.3	1.55
Cylinder	Carbon	0.15	0.15

Table 5: materials used for the different components.

The dead region was implemented as given in the specifications above. Z-overlapping was also implemented, the value for this was 0.3mm.

[5]percentage radiation length averaged over the active area of the module

[6]to simulate a power cable increasing in size along the Z-axis, a cone was used. To specify the radiation length of the cone it was given a diameter at z=0cm corresponding to 0.011 X_0 and at z=80cm a diameter corresponding to 7*0.11 X_0.

5.1 Remaining to be implemented.

What still remains to be added into DICE is electronic noise and random malfunctioning of strips (i.e. "DEAD" strips). This however is to be implemented in the digitisation step and therefore shouldn't hold up the simulations.