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Engineered Prototypes of the Barrel and Forward Single-Sided Silicon Modules of CMS: Milestone Report

J. Connotte,H. Esser,W.H. Gu,K. Luebelsmeyer, D. Pandoulas,R. Siedling,B. Wittmer

RWTH, I Physikalischees Institut, Aachen, Germany

M. DePalma, R. Ferorelli,S. My,G. Raso,P. Tempesta

INFN and Dipartimento di Fisica dell'Universita', Bari Italy

A. Elliot-Peisert,W. Glessing,R. Hammerstrom,M. Mannelli, B. Scmitt

CERN, Geneva, Switzerland

E. Catacchini,C. Civinini, R. D'Alessandro,E. Focardi, M. Meschini, G. Parrini, M. Pieri, E. Scarlini

INFN and Dipartimento di Fisica dell'Universita', Firenze, Italy)

E. Babucci, G.M. Bilei, S. Bizzaglia, B. Checcucci, N. Dinu, A. Santocchia, V. Postolache

INFN and Dipartimento di Fisica dell'Universita', Perugia, Italy

A. Basti,F. Bosi,U. Cazzola, R. Dell'Orso,G. Favati, A. Gaggelli, C. Gingu, A. Messineo,F. Raffaelli, G. Tonelli, P.G. Verdini

INFN and Dipartimento di Fisica dell'Universita', Pisa, Italy

Abstract

This note is intended to describe the main features of the first engineered versions of the basic single-sided detector modules for the barrel and forward silicon tracker of CMS.

1 Introduction

The Silicon Tracker of CMS is substantially made-out of two different types of detectors (single and double-sided) in two different geometries (rectangular/barrel and wedge-like/forward). The inner part of the system will be equipped with double-sided detectors while single-sided modules will instrument the outer radii of the tracker.

The detector modules will be precisely positioned in the supporting structures (wheels for the barrel and disks for the forward) fabricated in high modulous carbon fibre and incorporating cables and services.

A detailed study is under way on the supporting structures in order to guarantee a stability within tens of μm under the effects of gravity, assembly procedures,thermal cycles and heavy irradiation.

The position of each individual module in the tracker will be recorded during the assembly procedure and measured during data taking using tracks for alignment purposes. The position of each individual wheel and disk will be surveyed by optical means during the running of the experiment.

With detectors heavily irradiated and subject to high leakage currents we shall prevent the possibility of thermal runaway and other long-term effects affecting irradiated silicon by keeping the whole volume of the tracker at an operating temperature below 0^oC.

2 Requirements

The basic requirements of the detector modules can be summarized as follows:

- Cooling: the system should maintain the maximum temperature of the silicon detectors below -5^oC. The mechanics of the module should incorporate an efficient cooling system able to remove about 2.0 Watts of heat generated by the front-end electronics and an additional .5 Watts generated by the leakage currents of the irradiated detectors.
- Alignment and mechanical stability: the high performance required for the whole structure imposes stringent requirements on the single detector module. The silicon detectors should be internally aligned within 5 μm in the detector plane and within 30 μm in the coordinate perpendicular to the plane. The modules should be stable under gravity and thermal stress within a few μm.
- Low mass: the material of the tracker will significantly affect the performance of the electromagnetic calorimeter; we should minimize the weight and material budget of each detector component.
- Easy fabrication/assembly: a few thousand detector modules are foreseen; the fabrication procedure should be as simple as possible; the cost of each element should be properly taken into account; an easy assembly/disassembly procedure should be implemented.

The goal of this milestone is to provide a first set of engineered solutions to these problems for the single-sided detector modules.

3 Proposed Approach

The basic idea is to use a high conductivity K, high Young modulous E , low coefficient of thermal expansion CTE, carbon fiber composite as supporting element for the silicon detectors and the electronics unit.

Fibers with thermal conductivity as high as 1100W/^{o}Km are commercially available. Starting from prepreg (fibers AMOCO K1100X-2K and resin FIBERITE 954-3A Cyanate Ester) we have obtained thin sheets (0.5mm thick) with K between 400-500W/^{o}Km similar to Copper and E about 400GPa similar to Tungsten and its alloys. The CTE of this material along the fiber direction is less than $10^{-6}/^o$K and the radiation length, x_o, is high enough for our purposes: 25cm to be compared with the 35cm of the best materials (Beryllium and its alloys).

This carbon fiber composite is stiff enough to guarantee a good stability against gravity and handling stresses with a minimum contribution to the radiation budget. Stiffening ribs produced with the same material can be used to increase the inertia of the structure to further reduce the gravitational sagitta.

The low CTE prevents significant deformation and thermal stress when the structure will be cooled down from assembly (+21^{o}C) to running (-5^{o}C) temperature. The difference between the CTE of the CF element and the

CTE of silicon (4.67x10^{-6}/^{o}K) is small enough to allow the compensation by the thin layer of glue which is used to fix the silicon detectors to the CF sheet.

The very high thermal conductivity allows the use of the supporting element as heat bridge for the power dissipated by the electronics and by the silicon detectors. The CF supporting element will be in good thermal contact with the cooling tubes incorporated in the main supporting structures. The optimization of this interface is still under study. Preliminary FEA simulations confirmed by experimental measurements indicate that we could reduce the thermal gradient between the temperature of the coolant fluid and the temperature of the CF supporting element below 5 ^{o}C. Both sources of heat, the front-end chips and the silicon detectors, will be directly glued to the CF supporting element with thin layers of epoxy adhesive with high thermal conductivity, excellent dimensional stability and high dielectric strenght. A sample of these adhesives (Supreme 11ANHT by MASTER BOND) has been used for prototyping work. The glue is widely used in electronics ; it has a K of 2.8W/^{o}Km and a dielectric strenght greater than 15KV/mm. Details of these components can be found in the technical appendix.

For the positioning of the silicon detectors we plan to use aluminum precision inserts glued to the supporting CF element under a coordinate measuring machine (CMM). Precise alignment marks engraved in the silicon detectors are used to determine the relative position of the silicon sensors with respect to the positioning inserts. Preliminary tests indicate that with this procedure the strips of the silicon detectors can be parallel within 3μm and their position with respect to the positioning inserts can be specified within 5μm and measured within 2μm.

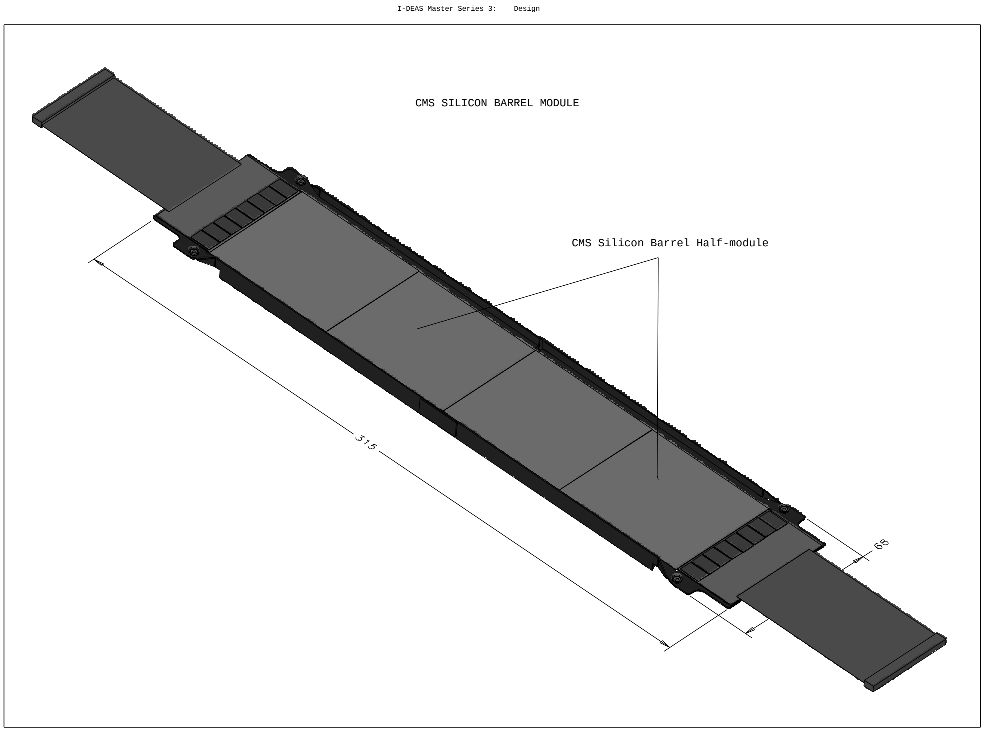

Figure 1: CMS Silicon barrel module

4 The Barrel Detector Module

A barrel detector module is fabricated by coupling together two half- modules joint by stiff carbon fibre elements (Fig.1).

Each half-module consists of two silicon detectors glued together whose strips are daisy-chained and coupled to the read-out electronics (Fig.2 and Fig.3).

The high conductivity carbon fiber support is shown in Fig. 3. The first prototypes have been fabricated by machining a CF sheet, .5mm thick, and by glueing together the stiffening ribs (.5x8x127mm^2) to the supporting plate. The weight of the CF supporting element including the glue is 2.4g. We are investigating the feasibility of a molding procedure to fabricate the supporting element in a single process.

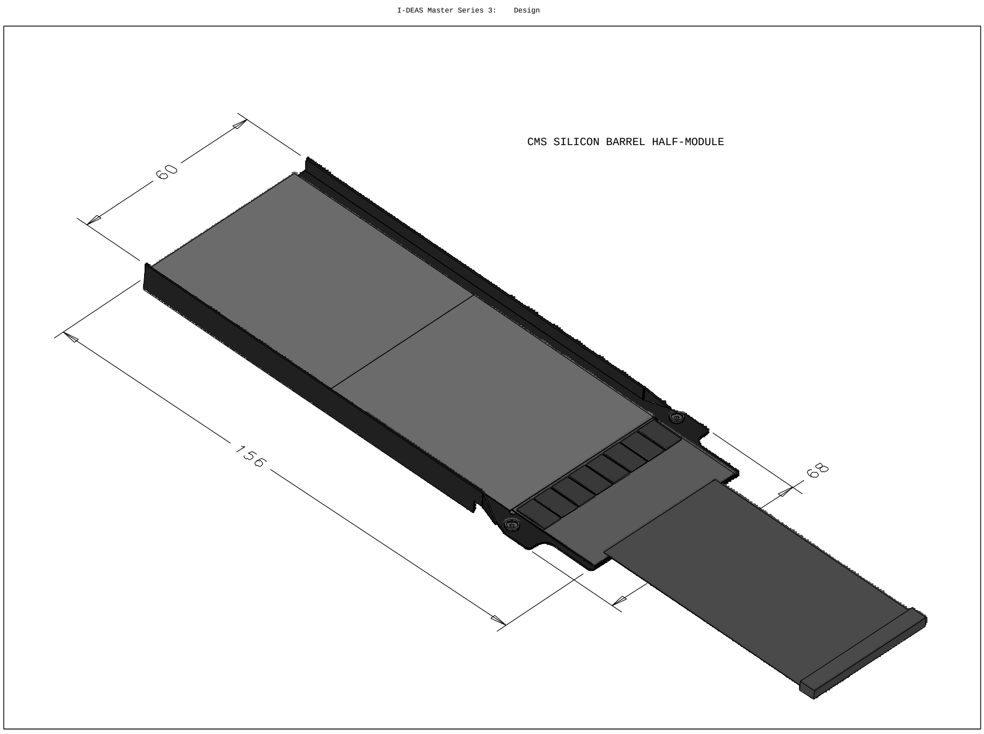

Figure 2: CMS Silicon barrel half-module

The positioning pins consist of two small bushes machined in brass and precisely glued to the supporting element under a CMM. The bushes feature precise holes whose centers defines the origin and the main axis of the reference frame for the alignment(Fig.4).

The hybrid circuit housing the read-out electronics is directly glued to the CF supporting element. The positioning pins are used in this case to align the input pads of the preamplifiers with respect to the bonding pads of the detectors to make easier the automatic ultrasonic bonding procedure.

The silicon detectors, with a size of 5.4x6.4cm^2, are first glued together with an appropriate jig under the CMM. Following a detailed assembly procedure, the parallelism of the strips is guaranteed within $3\mu m$ and surveyed at the $2\mu m$ level.

A specific jig is used to couple the pair of silicon detectors to the supporting element incorporating the positioning pins and the hybrid circuit. The silicon detectors are glued on top of the supporting element with a thin layer of high conductivity isolating glue. The surface of contact between silicon and CF is large enough (2x125mm^2) to guarantee an efficient removal of the heat self-generated in the silicon after heavy irradiation. The clearance between the bonding pads and the stiffening ribs is large enough to allow an easy microbonding path for most commercially available machines.

A few components of these first engineered prototpyes are slightly different from the final detector module of CMS. In particular we are now using a standard ceramic hybrid to house and service the Premux128 amplifiers while a low mass metallized kapton hybrid is planned for the final APV chip. The weight of the half modules fabricated with ceramic hybrids and relatively bulky connectors is 17.5g. We expect that the use of low mass hybrids and connectors will reduce this figure to less than 15g. As foreseen the gravitational sagitta of the full-size module is below $5\mu m$.

The assembly procedure and the specs of all components used to fabricate modules including the assembly jigs will be specified in detail. We did a preliminary exercise for the assembly procedure and for the documentation accompanying the fabrication of each module. In the technical appendix we present an example of this kind of documents.

The prototypes so far fabricated will be used for a series of measurements and studies aimed at optimizing all details. We are in particular interested in optimizing the cooling performance of each module. A preliminary FEA

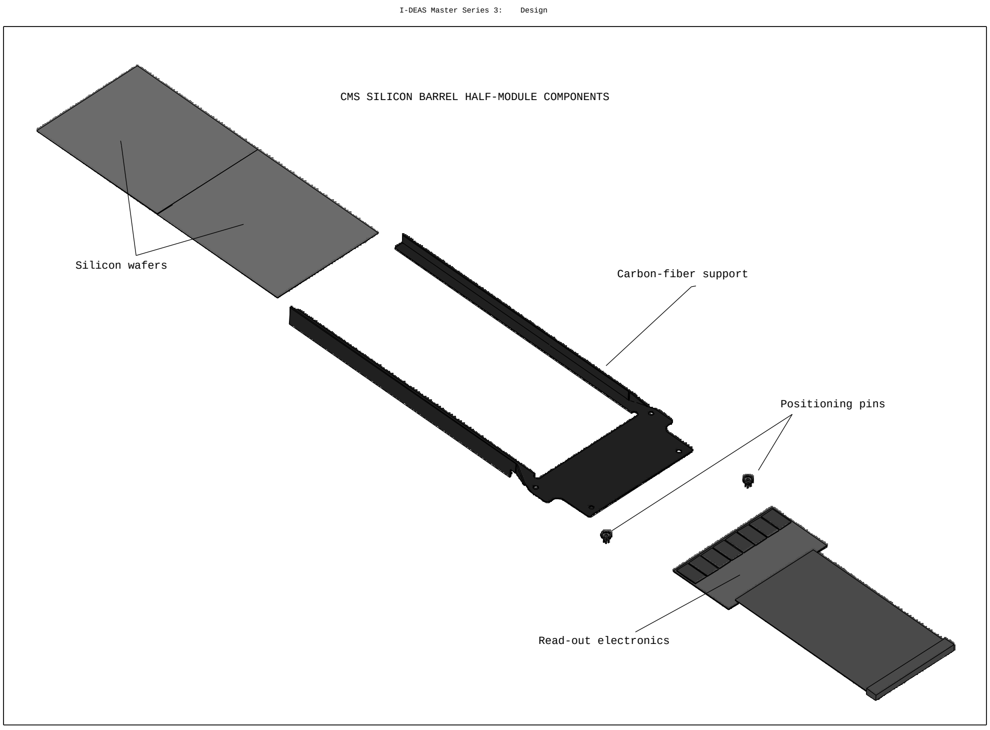

Figure 3: CMS Silicon barrel half-module components

calculation of the thermal gradients expected in the modules has been performed assuming realistic values for the thermal resistances at each interface. We obtain a maximum gradient between the silicon detectors and the carbon fiber supporting element of about 5^oC (Fig.5 and Fig.6).

The technical drawings of the barrel module are shown in fig. 7 and fig.8

5 The Forward Detector Module

Two different types of silicon detector modules will be used for the forward disk. The wafers are arranged as two sets of 36 modules each one covering the full azimuth: single detector modules (type 1) will be used in the inner set while the outer set will be equipped with two-detector modules (type 2). The fabrication of the two types of modules is very similar. Here we describe in detail type 2 modules.

These modules consist of two Si wedge-shaped detectors glued together whose strips are daisy-chained and coupled to the read-out electronics (Fig.9). The detectors are precisely positioned inside a carbon fiber support (”carrier”), fig.10. The carriers consist of three mouldings which are positioned and glued together in a jig. The parts holding the wafers (side rails) are made up of six layers of high modulous, high thermal conductivity unidirectional (K 1100-x) fibre prepreg. The hybrid part is made up of three layers of similar material (fig.11). The prepreg uses a cyanate ester resin matrix because of its superior stability at different moisture levels. Since they are made in several parts the fibre direction in the carriers can be more easily arranged for optimum thermal conductivity for each part.The preferred heat path both for detectors and electronics is led directly to the cooling ring incorporated in the disk.

The module is fixed to the structure with screws engaged in metal inserts. A thermally conducting compound will be also used at the thermal interfaces. Wafers will be accurately positioned on the carriers using the dowel holes and slot near the hybrid as reference. The carriers will be aligned to the overall structure by using positioning pins.

The result of a preliminary simulation of the cooling performance is shown in fig.12. The maximum temperature gradient within a module is estimated to be in the range 5-6 ^oC, a value which is considered satisfactory for our purposes.

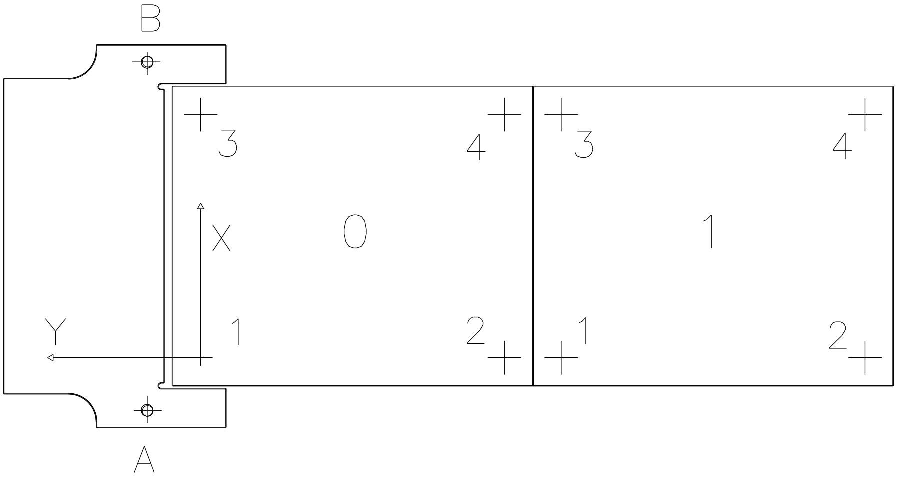

Figure 4: CMS Silicon barrel half-module precision holes location

6 Conclusion

Although several details are still to be optimised, we consider these first engineered prototypes of the single-sided modules a realistic approach to the final design foreseen for the Technical Design Report at the end of 1997.

7 Acknowledgments

We would like to acknowledge the following people for the help provided in the different steps of the fabrication process: G.Sala, M.Franco (Bari), L.Corucci, A.Del Colletto, P.Mammini, A.Orsini, A.Profeti, E.Pucciarelli, E.Troiani (Pisa)

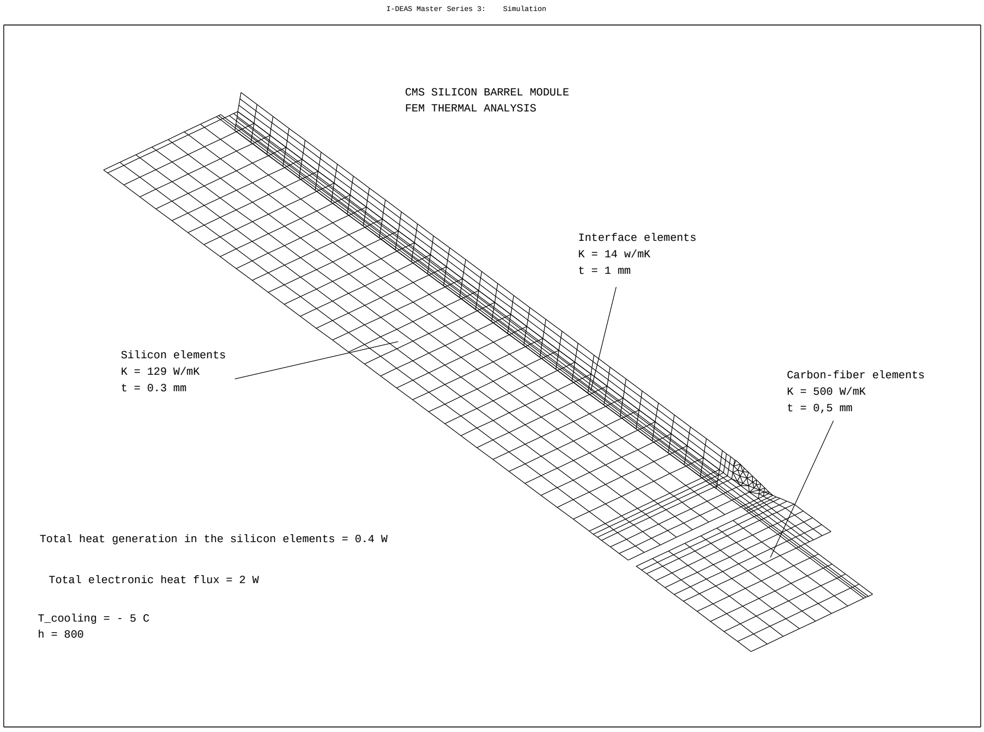

Figure 5: CMS Silicon barrel module FEM thermal analysis

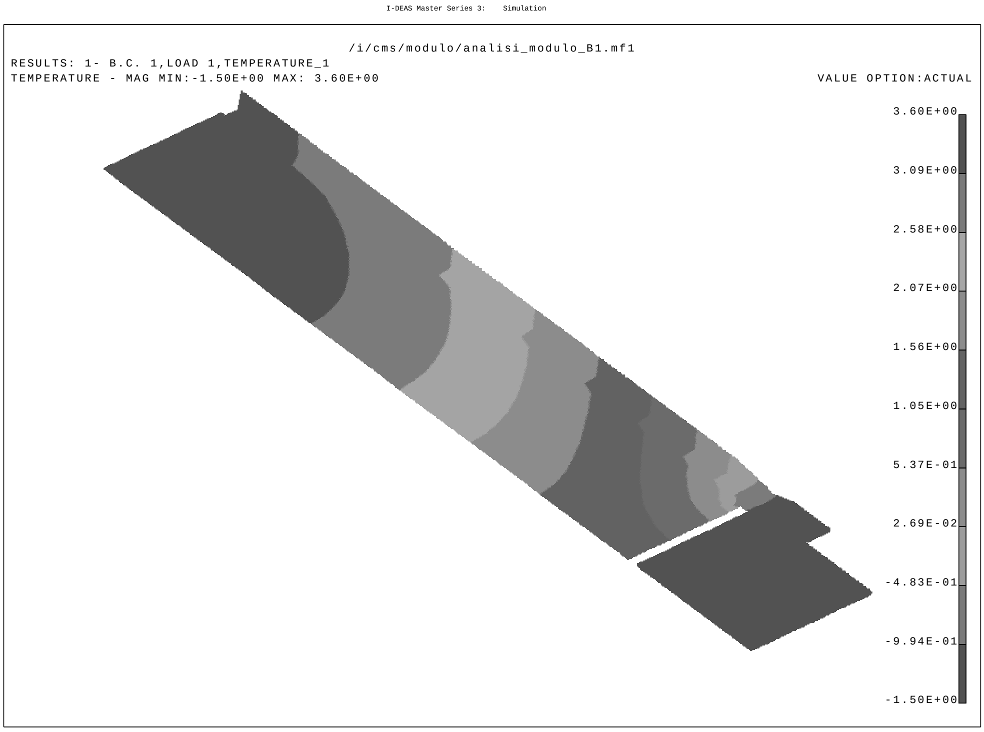

Figure 6: CMS Silicon barrel temperature analysis

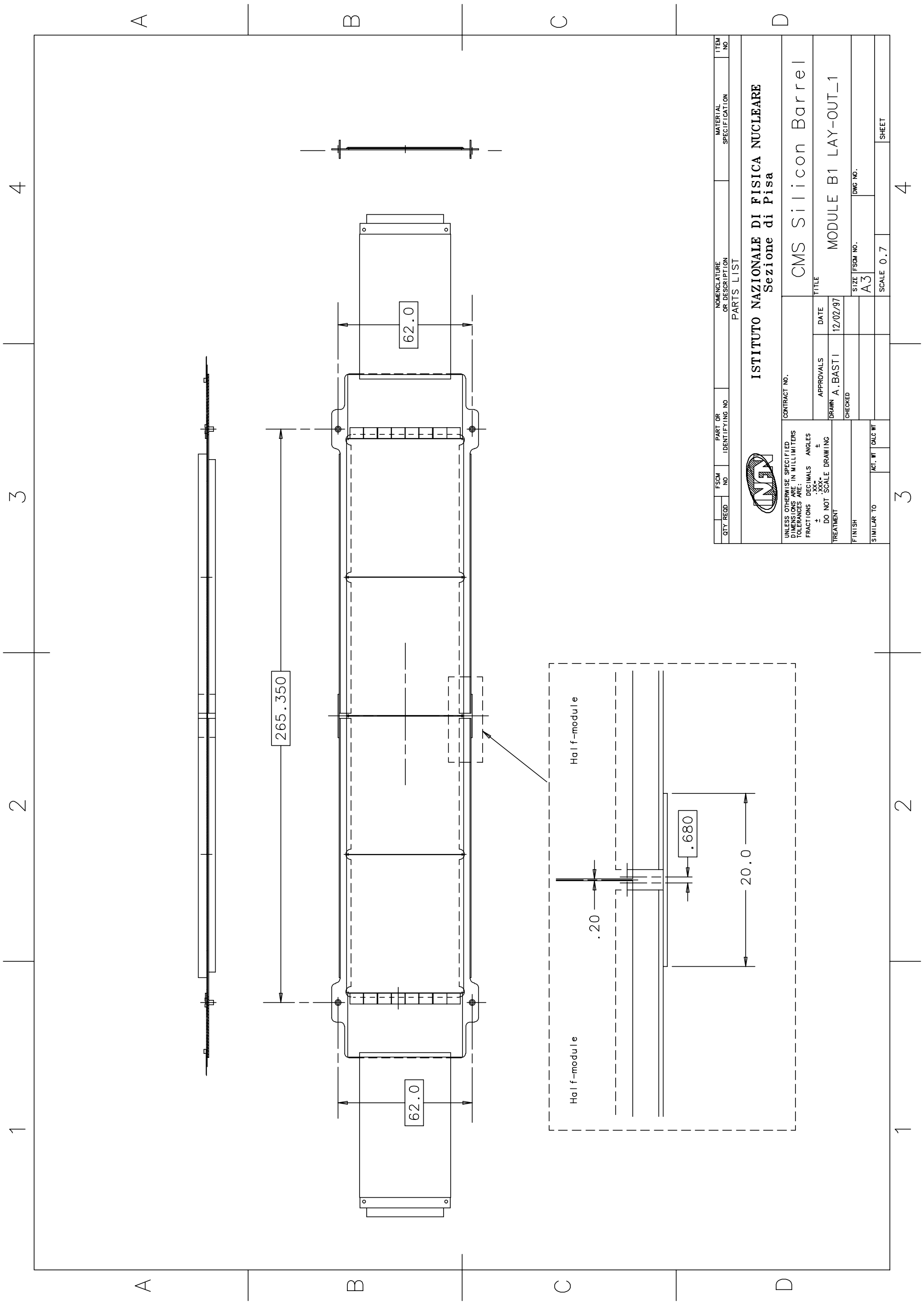

Figure 7: CMS Silicon barrel module layout

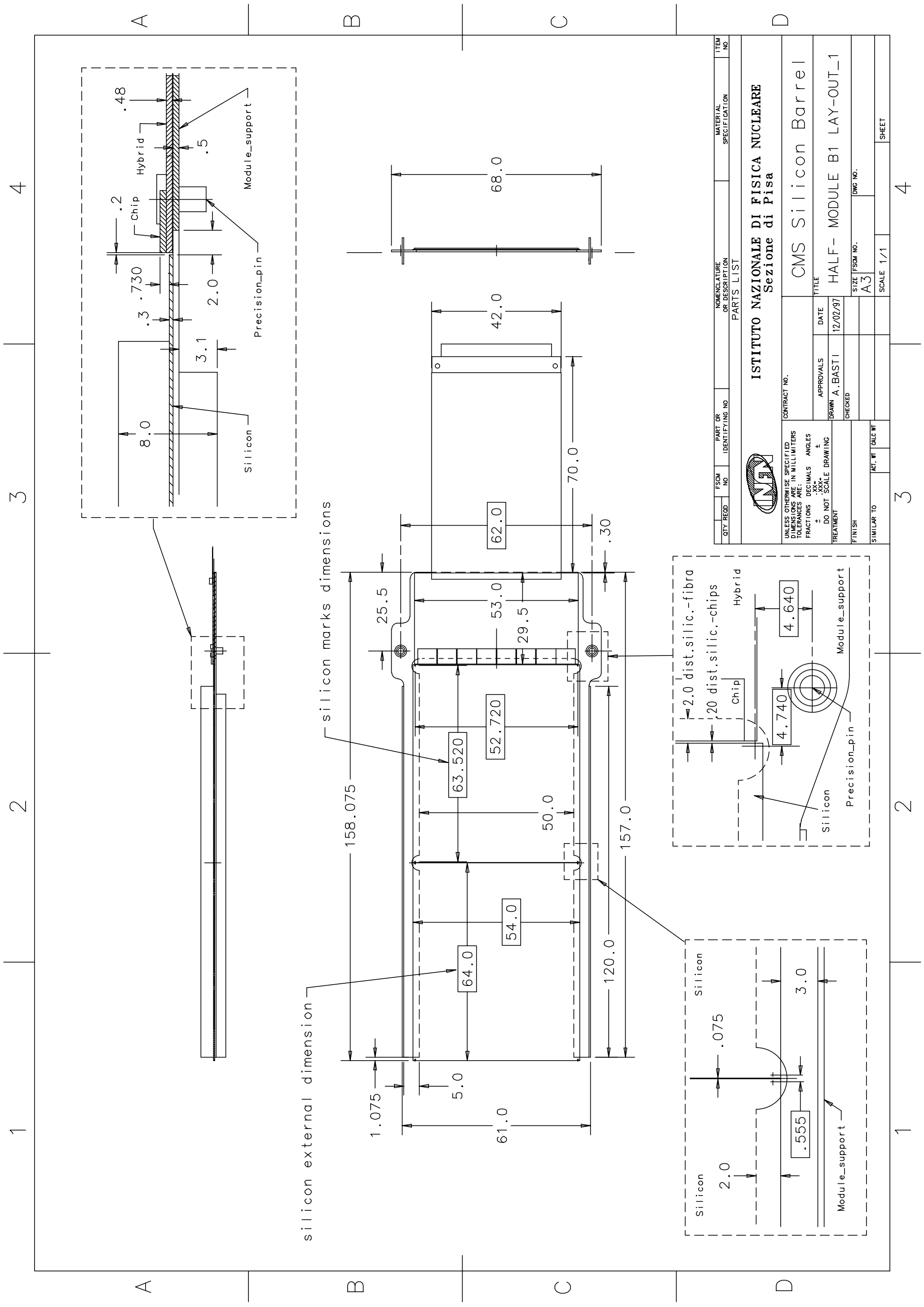

Figure 8: CMS Silicon barrel half-module layout

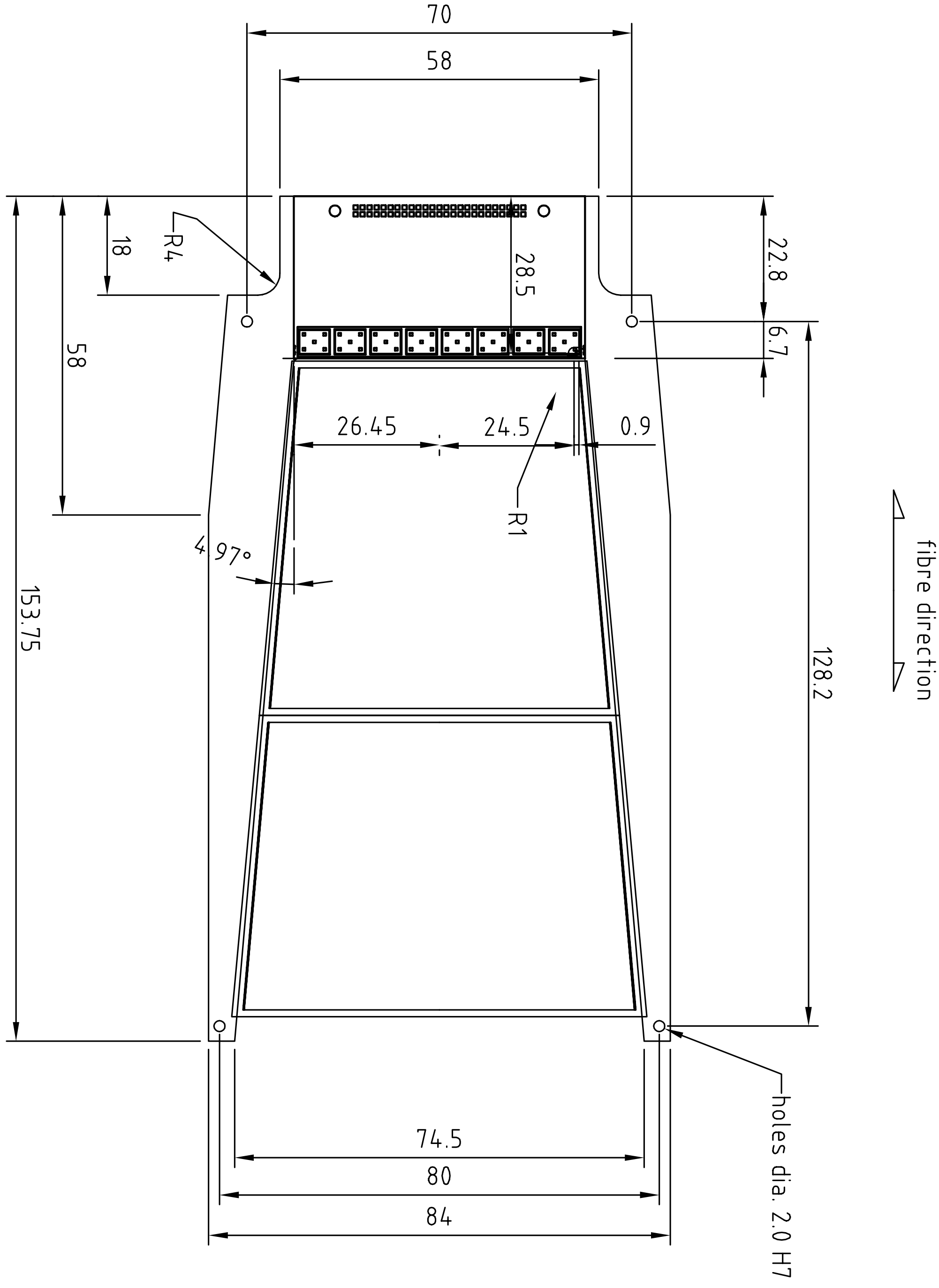

Figure 9: CMS Si forward module

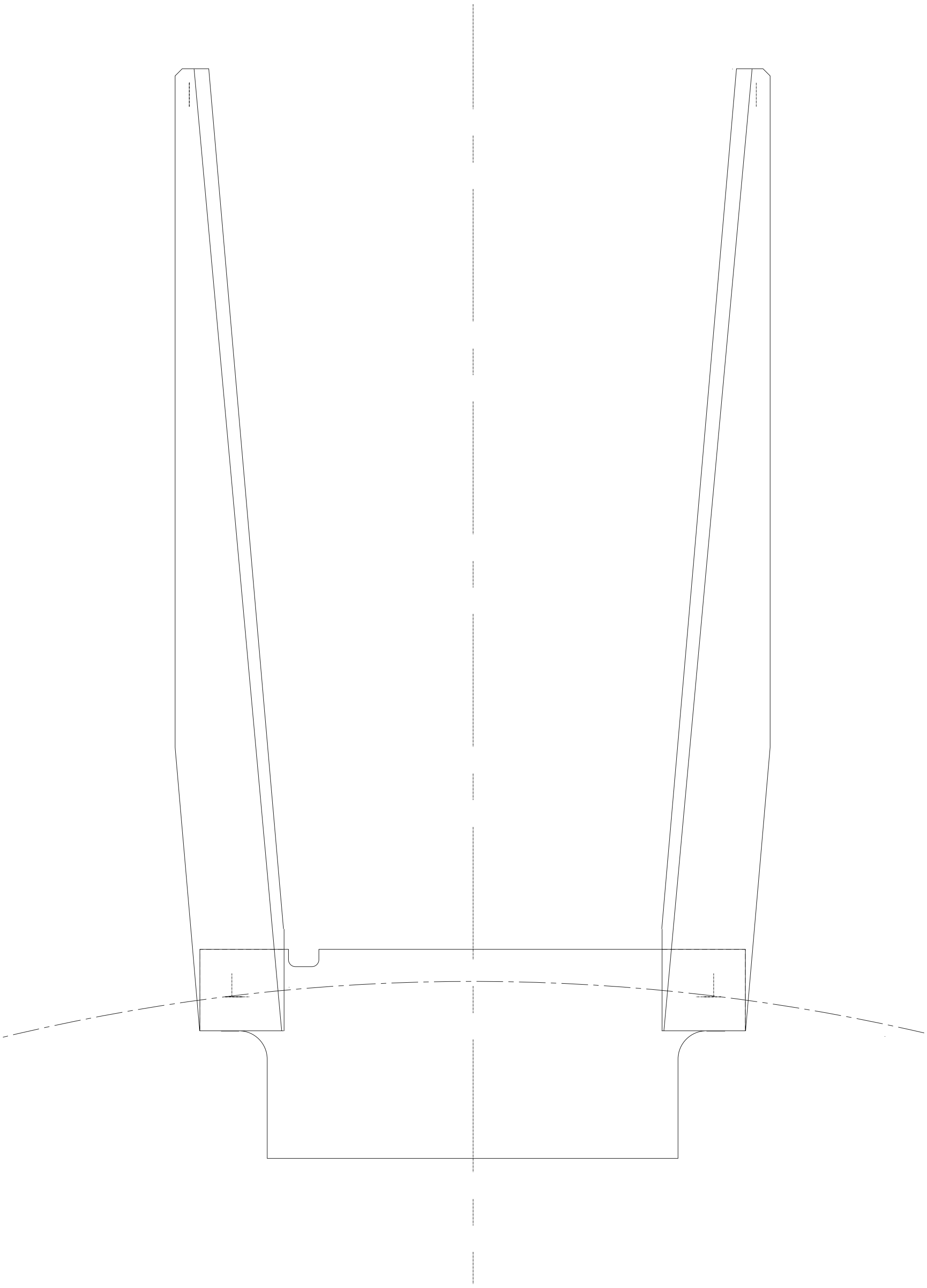

Figure 10: CMS Si forward CF support

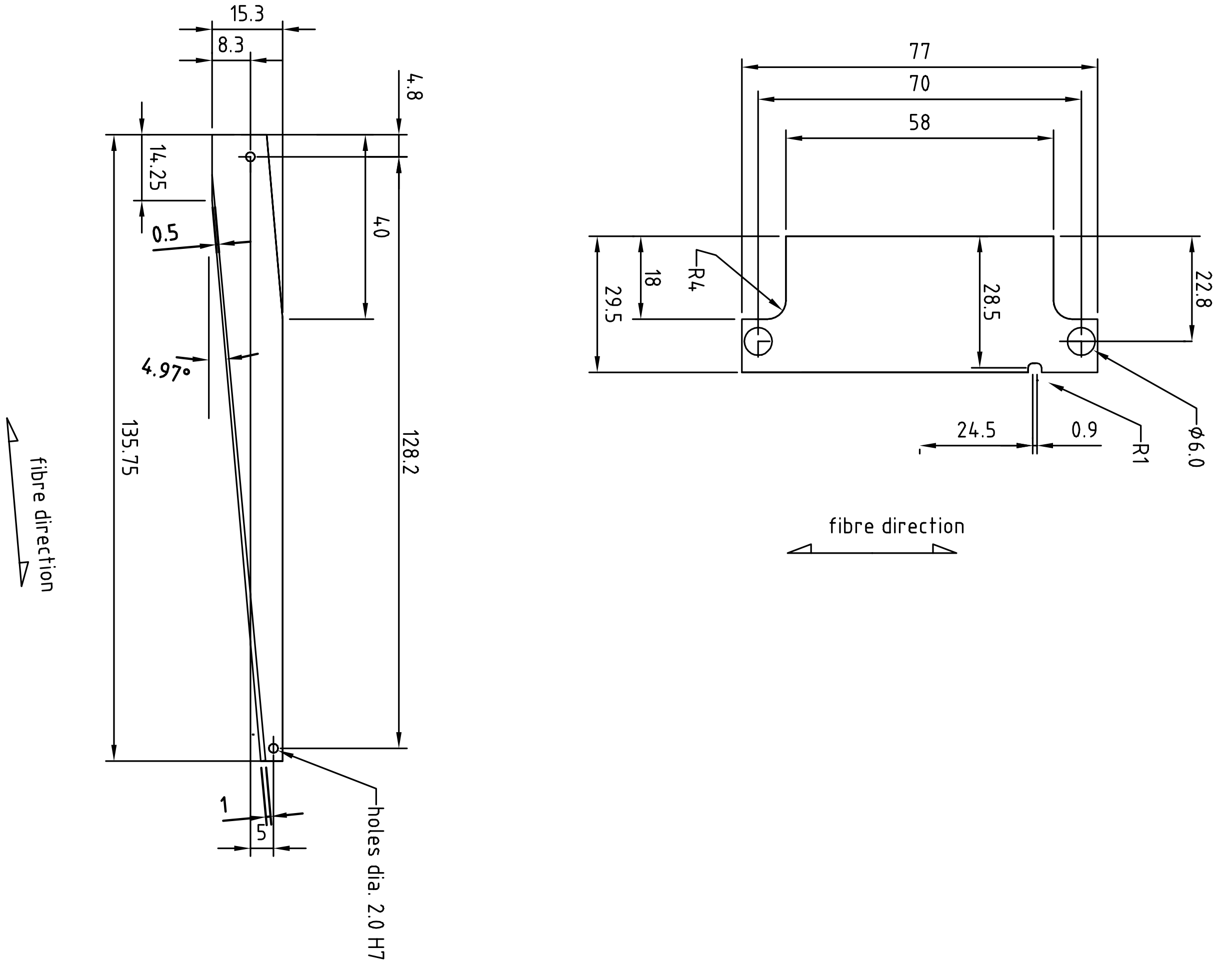

Figure 11: CMS Si forward CF dimensions

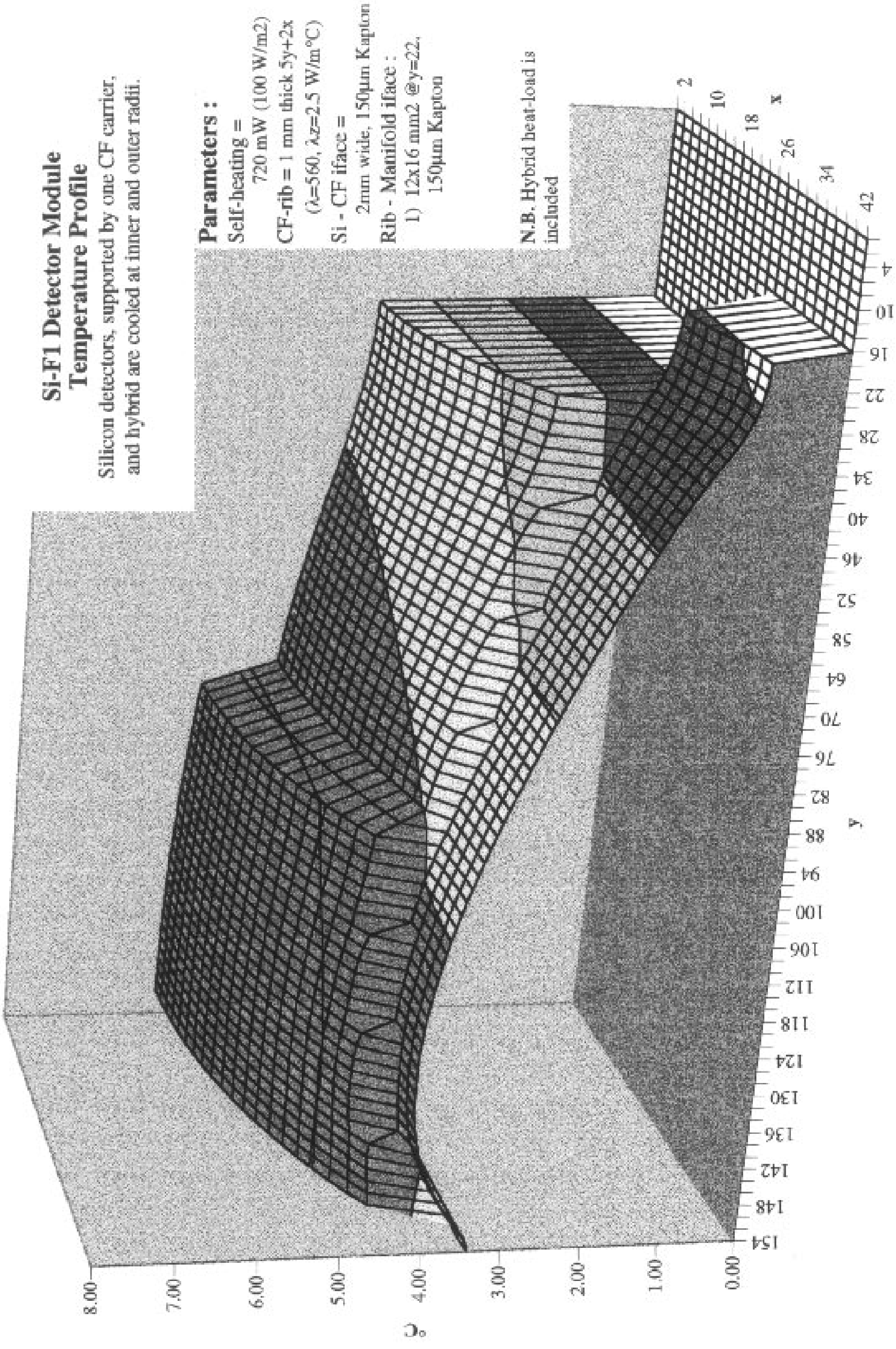

Figure 12: CMS Silicon barrel temperature profile