April 27, 1999

MAX-PLANCK-INSTITUT F"UR PHYSIK
WERNER-HEISENBERG-INSTITUT

SCT Forward Modules: Baseline Design and Thermal Properties

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Abstract

Type	R_{inner} (mm)	R_{outer} (mm)	detectors	number
outer	438	560	2x(W31,W32)	936
middle 12	334	453	2x(W21,W22)	560
middle 6	399	435	2x(W22)	80
inner	258	332	2x(W12)	400

Table 1: Types of forward modules: R_{inner} and R_{outer} is the inner and outer radius of the detector area, detectors tells the number and type of detectors required and number the number of module needed

1 Introduction

2 Baseline Design

2.1 Module types

The forward geometry [1] implies the use of for different module types:

- **outer**: used in the outer ring of the disk, made out of four detectors.
- **middle 12**: used in the middle ring, using four detectors
- **middle 6**: used in the middle ring where only about have of the area needs to be covered. Layout is identical with the middle 12 module, but only the detector pair at the larger radius is used (this reduces the length of the module from 12 to 6 cm).
- **inner**: used in the inner ring. Only one pair of detectors is needed.

More details are listed in table 1.

2.2 Design

The basic design is based on two (one) pair of single sided detectors with radial strips, arranged in two adjacent planes with 40 mrad stereo angle. The detectors are mounted on a cross shaped support structure based on a 12 mm wide heat conductor made of pyrolytic graphite and AlN pieces for support and stiffening. The readout electronics is on a hybrid mounted at the end of the detectors. Two mounting points are foreseen, one at the end, one in the hybrid/detector interface region. The mounting points act as cooling contacts, however for the short modules with 2 detectors only (middle 6 and inner) only one cooling contact is foreseen, at the hybrid/detector interface. Details of the design are shown in Figs. 1-9.

3 Thermal Properties

The module design should allow to keep the detectors at temperatures around -7^o to reduce reverse annealing. The main concern, however, is thermal runaway. Since the leakage current increase strongly with rising temperature uncontrolled self heating could occur if the heat produced by these currents cannot be removed.

3.1 Requirements

The nominal power density Q_0 of irradiated silicon (3×10^{14}p/cm^2) is 120 W/m^2 at 0^{o}C. For safety reasons it is required that the module can be operated up to twice this value.

3.2 FEA calculations

The thermal properties were simulated using FEA analysis. Following assumptions were made:

- The module is cooled entirely by the cooling blocks. No heat transfer to and from the ambient gas is allowed.
- The coolant is assumed to be a fluorocarbonat with 3750 W/m^2 heat transfer coefficient. Baseline coolant temperature is -15^{o}C, although the cooling specifications allow for lower temperatures.
- The cooling block properties are taken from a separate FEA analysis. Typically the thermal resistance is 3 K/W for the detector and hybrid contacts and a cross term of 0.6 K/W modeling the temperature rise of the detector contact due to the hybrid power. The high cooling block is simulated.
- The temperature dependence of the silicon power density is modeled using:

$$Q(T) = Q_0 \frac{T^2 \exp\left(-\frac{E_g}{2kT}\right)}{T_0^2 \exp\left(-\frac{E_g}{2kT_0}\right)} \tag{1}$$

  For silicon, the nominal band gap is $E_g = 1.1$ eV. Measurements of irradiated silicon detectors indicate a slightly larger value ranging from 1.15 to 1.26 eV. As worst case 1.26 eV is used in the calculations.

The thermal conduction coefficients and dimensions of various material can be found in table 2. Recently the power produced by the readout electronics on the hybrid has increased from 4.5 W to 7 W (worst case). This leads to an deterioration of the thermal properties. Firstly the heat flow from the hybrid to the detector part of the block is increased, resulting in a higher temperature of the cooling block. Secondly some heat flows via the fan-ins from the hybrid to the detectors.

material	conduction W/m/K	thickness (mm)	comment
Silicon	136	0.3	outer/middle
		0.26	inner
TPG	1700	0.5	thinned to 0.225 mm at joints
TPG	8		transverse
AlN	180	0.5	two layers of 0.225 mm
glue	0.42	0.1	Silicon/TPG
glue	1.0	0.05	TPG/AlN
BeO	260	0.5	Hybrid
grease	0.9	0.03	cooling contact
quartz	1.5	0.25	pitch adaptor

Table 2: Material properties used in simulation

3.3 Results

The runaway curves for the outer module with 4.5 and 7 W hybrid power are shown in Fig. 10. With 4 W hybrid power the module just meets the requirements (at $Q_0 = 240\ W/m^2$). However, with 7 W hybrid power runaway occurs slightly below the safety margin (at $Q_0 = 210\ W/m^2$. As shown in Fig. 11 a slight decrease of the coolant temperature to $\approx -16^oC$ allows to operate the module safely.
The inner ring modules are more critical. Firstly they have only one cooling contact. Secondly the use of thinner detectors (260 μm) reduces the heat conductivity in the silicon itself. As seen in Fig. 12 even with 4 W hybrid power the module fails the specs (runaway at $Q_0 = 180\ W/m^2$). With 7 W hybrid power the situation is even worse ($Q_0 = 140\ W/m^2$). While with 4 W power a reduction of the coolant temperature to $\approx -18^oC$ cures the problem (Fig. 13), for the 7 W case a rather low coolant temperature of -21^{o}C is necessary. An improved cooling block design reducing the cross talk between hybrid and detector cooling is needed for this module type. Similar problems are expected for the short middle ring module, which also has one cooling contact only.

3.4 Hybrid Substrate

All the simulations are based on the hybrid made from BeO. Alternative hybrid designs are proposed, e.g. a Kapton hybrid on an graphite encapsulated TPG substrate. The higher thermal conductivity should offer some advantage. Figure 15 shows a simulation with the standard BeO hybird and the TPG hybrid. This simulation does not accurately simulate the cooling block/coolant interface, so the point of runaway has no meaning. However, it is evident that the performance improves using the TPG hybrid.

References

[1] T. Jones, *Forward SCT Silicon Microstrip Detector Layout*, Draft, July 22 1998

SCALE 16:1

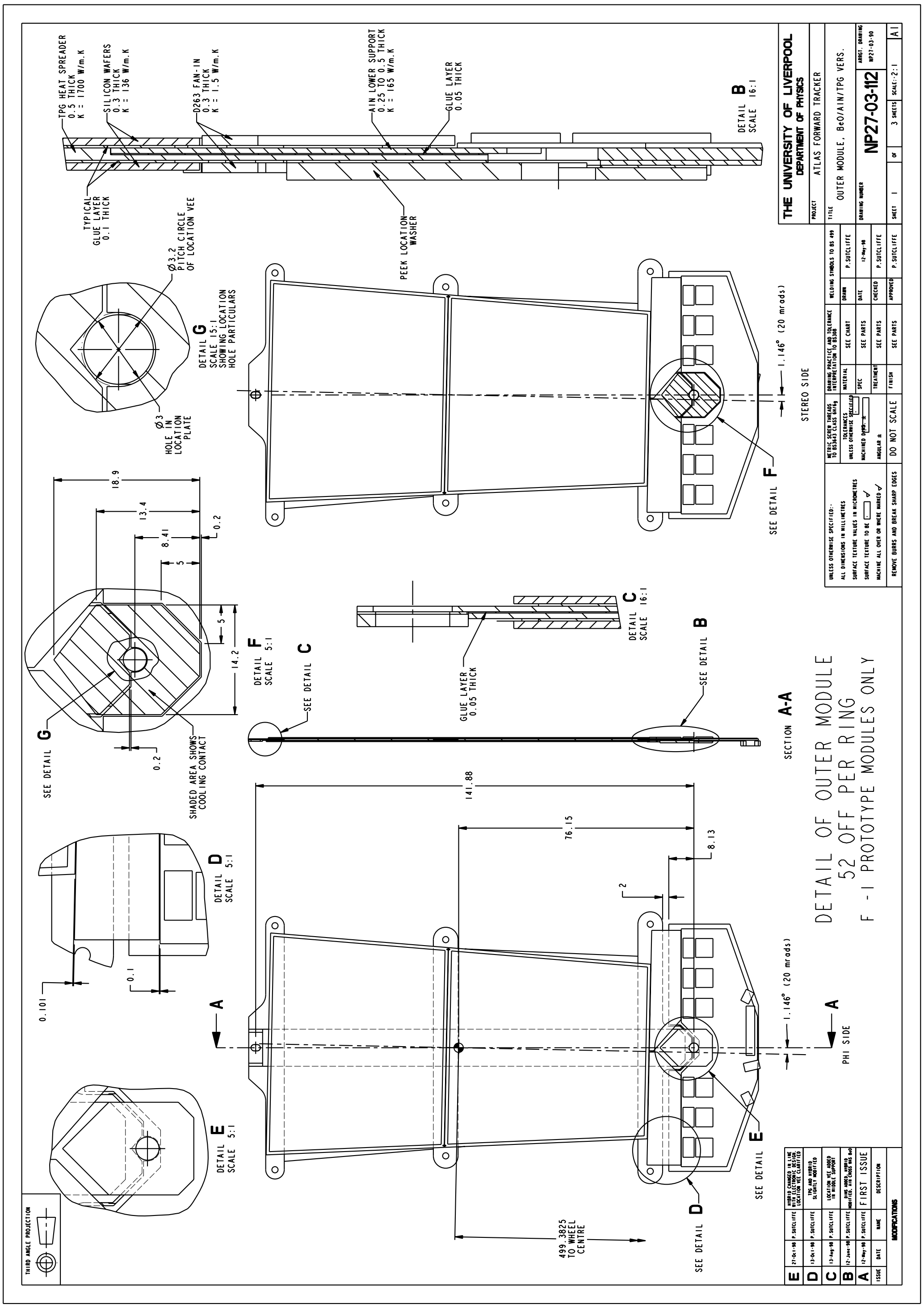
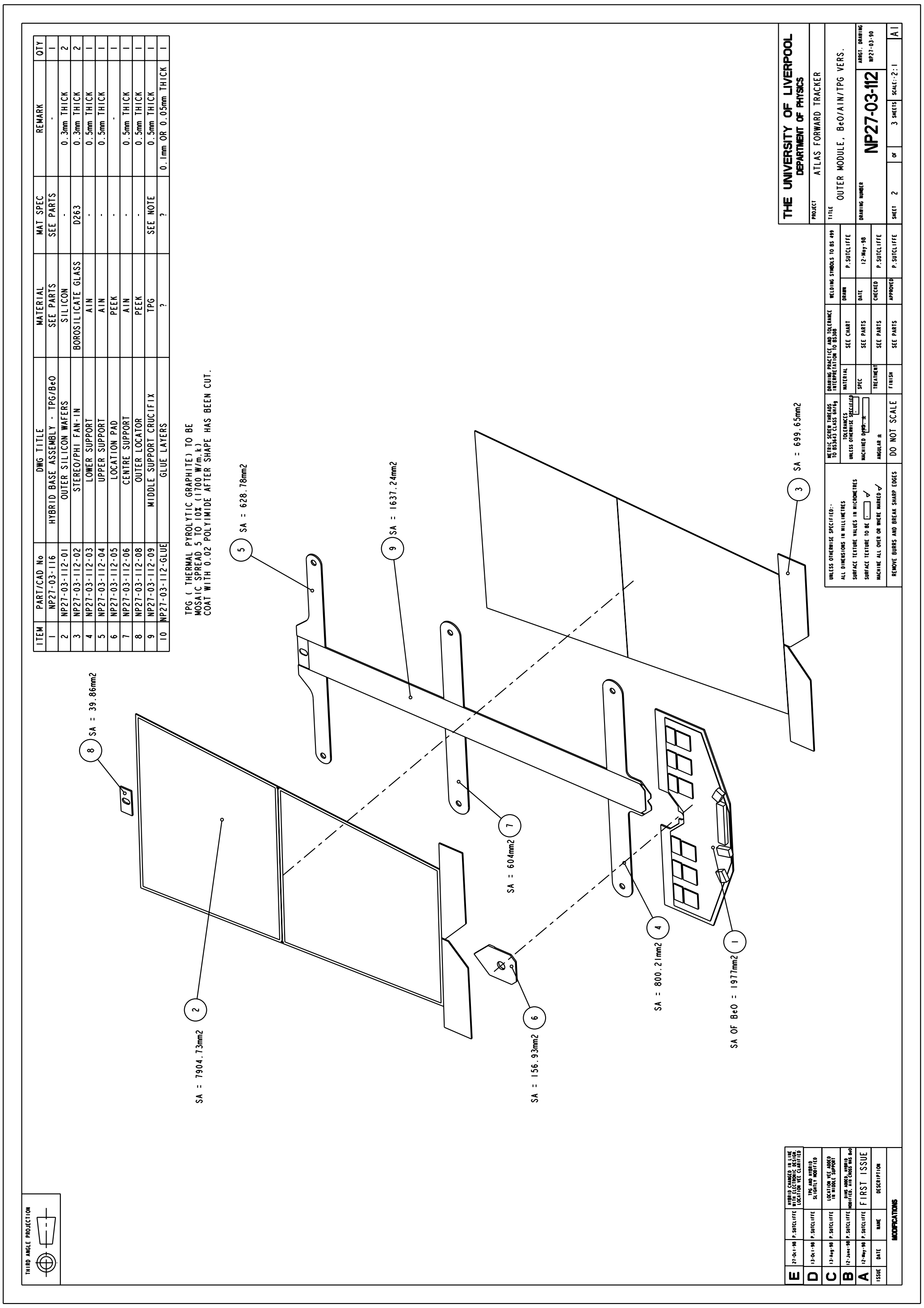


Figure 1:


ITEM | PART/CAD No | DWG TITLE | MATERIAL | MAT SPEC | REMARK | QTY
1 | NP27-03-116 | HYBRID BASE ASSEMBLY - TPG/BeO | SEE PARTS | SEE PARTS | - | 1
2 | NP27-03-112-01 | OUTER SILICON WAFERS | SILICON | - | 0.3mm THICK | 2
3 | NP27-03-112-02 | STEREO/PHI FAN-IN | BOROSILICATE GLASS | D263 | 0.3mm THICK | 2
4 | NP27-03-112-03 | LOWER SUPPORT | AlN | - | 0.5mm THICK | 1
5 | NP27-03-112-04 | UPPER SUPPORT | AlN | - | 0.5mm THICK | 1
6 | NP27-03-112-05 | LOCATION PAD | PEEK | - | - | 1
7 | NP27-03-112-06 | CENTRE SUPPORT | AlN | - | 0.5mm THICK | 1
8 | NP27-03-112-08 | OUTER LOCATOR | PEEK | - | 0.5mm THICK | 1
9 | NP27-03-112-09 | MIDDLE SUPPORT CRUCIFIX | TPG | SEE NOTE | 0.5mm THICK | 1
10 | NP27-03-112-GLUE | GLUE LAYERS | ? | ? | 0.1mm OR 0.05mm THICK | 1
TPG (THERMAL PYROLYTIC GRAPHITE) TO BE
MOSAIC SPREAD 5 TO 10X (1700 W/m.k)
COAT WITH 0.02 POLYIMIDE AFTER SHAPE HAS BEEN CUT.
SA : 39.86mm2
SA : 628.78mm2
SA : 1637.24mm2
SA : 699.65mm2
SA : 604mm2
SA : 7904.73mm2
SA : 156.93mm2
SA : 800.21mm2
SA OF BeO : 1977mm2
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DEPARTMENT OF PHYSICS
ATLAS FORWARD TRACKER
OUTER MODULE. BeO/AlN/TPG VERS.
NP27-03-112
DO NOT SCALE
FIRST ISSUE
MODIFICATIONS
THIRD ANGLE PROJECTION

Figure 2:

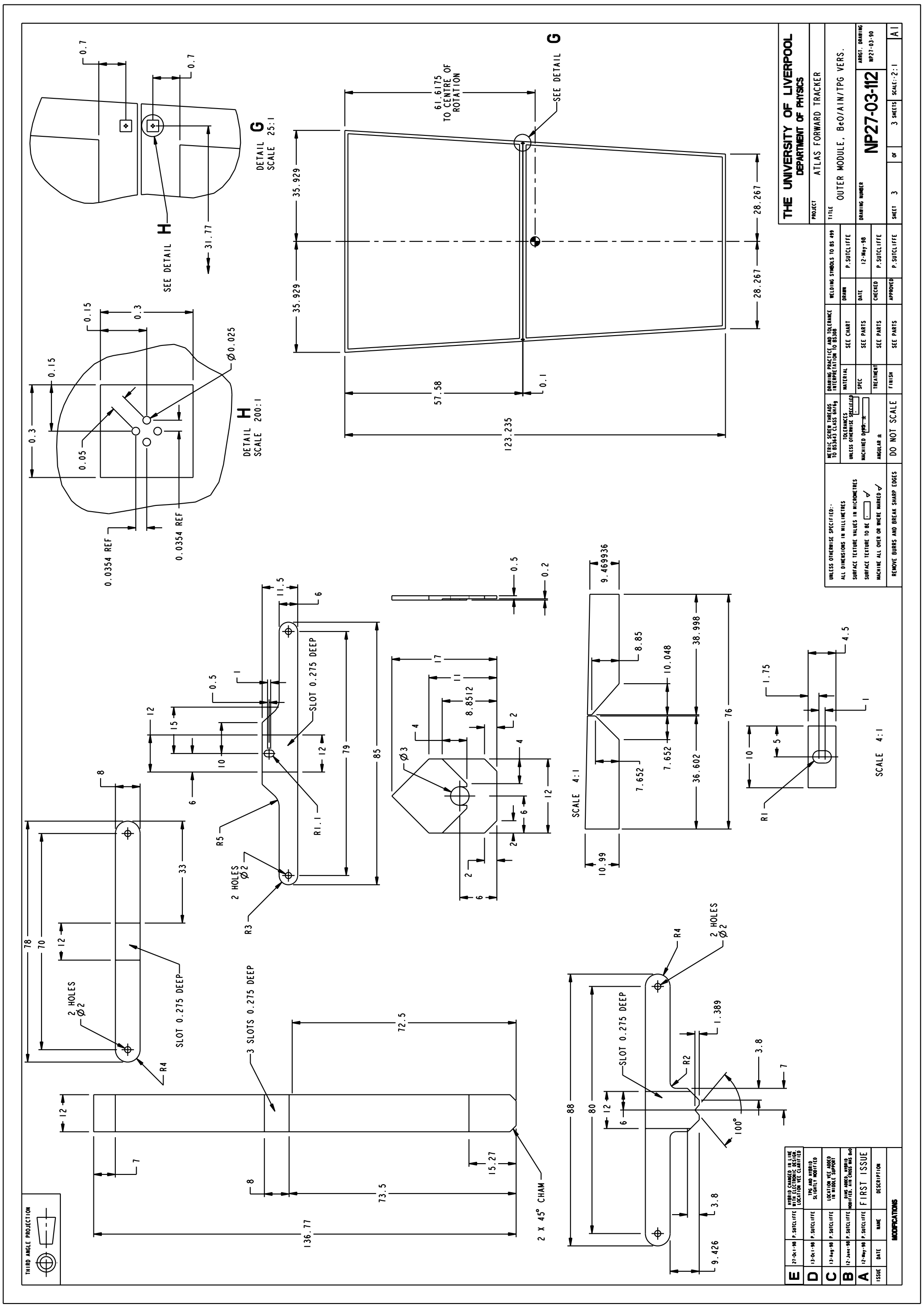

THE UNIVERSITY OF LIVERPOOL
DEPARTMENT OF PHYSICS
ATLAS FORWARD TRACKER
OUTER MODULE, BeO/AlN/TPG VERS.
NP27-03-112
DO NOT SCALE
THIRD ANGLE PROJECTION
MODIFICATIONS
FIRST ISSUE
DETAIL G SCALE 25:1
DETAIL H SCALE 200:1
SEE DETAIL G
SEE DETAIL H
SLOT 0.275 DEEP
3 SLOTS 0.275 DEEP
2 X 45° CHAM
SCALE 4:1

Figure 3:

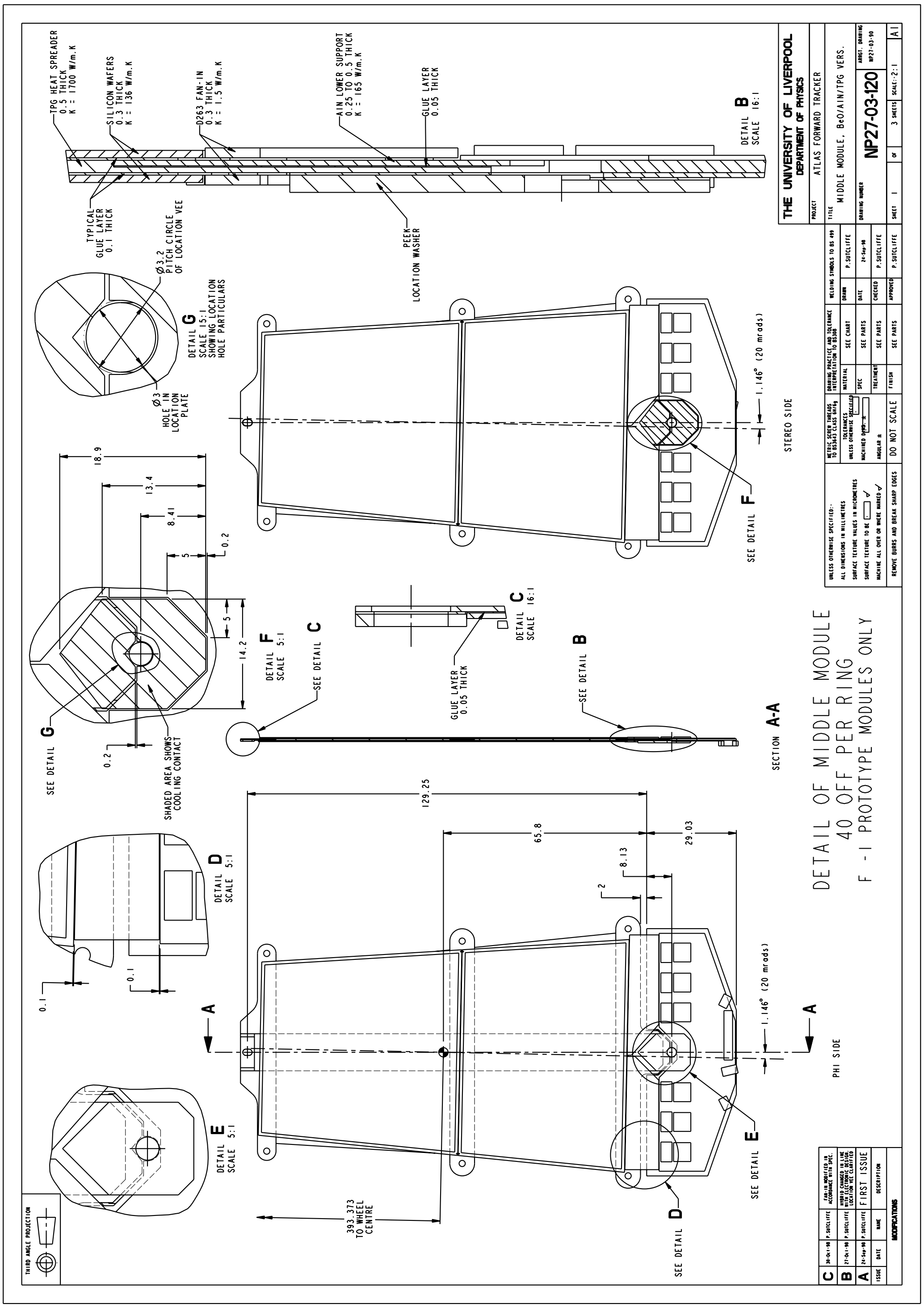
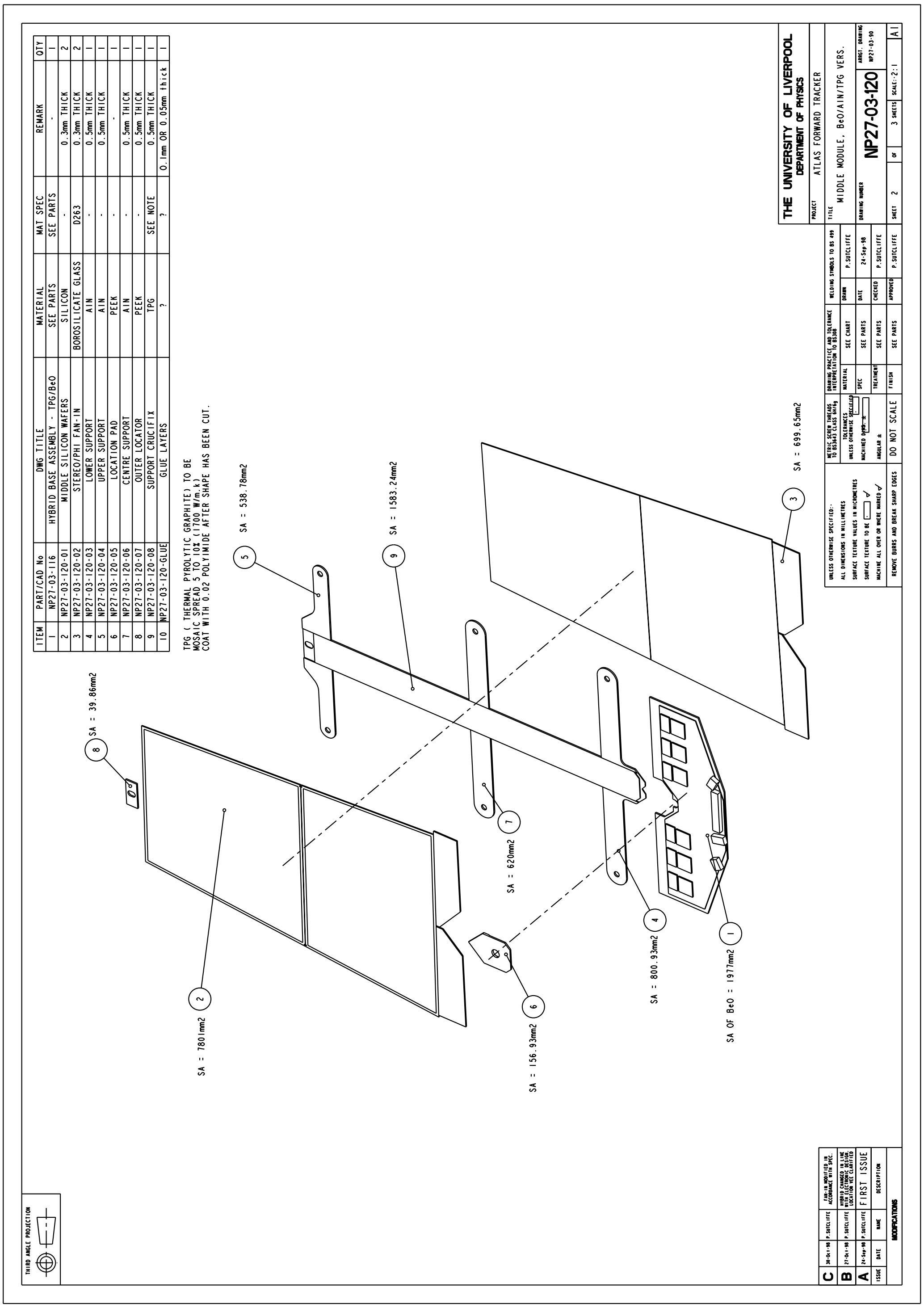

DETAIL OF MIDDLE MODULE
40 OFF PER RING
F -1 PROTOTYPE MODULES ONLY
THE UNIVERSITY OF LIVERPOOL
DEPARTMENT OF PHYSICS
ATLAS FORWARD TRACKER
MIDDLE MODULE, BeO/AlN/TPG VERS.
NP27-03-120
STEREO SIDE
PHI SIDE
SECTION A-A

Figure 4:


ITEM | PART/CAD No | DWG TITLE | MATERIAL | MAT SPEC | REMARK | QTY
1 | NP27-03-116 | HYBRID BASE ASSEMBLY - TPG/BeO | SEE PARTS | SEE PARTS | - | 1
2 | NP27-03-120-01 | MIDDLE SILICON WAFERS | SILICON | - | 0.3mm THICK | 2
3 | NP27-03-120-02 | STEREO/PHI FAN-IN | BOROSILICATE GLASS | D263 | 0.3mm THICK | 2
4 | NP27-03-120-03 | LOWER SUPPORT | AlN | - | 0.5mm THICK | 1
5 | NP27-03-120-04 | UPPER SUPPORT | AlN | - | 0.5mm THICK | 1
6 | NP27-03-120-05 | LOCATION PAD | PEEK | - | - | 1
7 | NP27-03-120-06 | CENTRE SUPPORT | AlN | - | 0.5mm THICK | 1
8 | NP27-03-120-07 | OUTER LOCATOR | PEEK | - | 0.5mm THICK | 1
9 | NP27-03-120-08 | SUPPORT CRUCIFIX | TPG | SEE NOTE | 0.5mm THICK | 1
10 | NP27-03-120-GLUE | GLUE LAYERS | ? | ? | 0.1mm OR 0.05mm thick | 1
TPG (THERMAL PYROLYTIC GRAPHITE) TO BE
MOSAIC SPREAD 5 TO 10Z (1700 W/m.k)
COAT WITH 0.02 POLYIMIDE AFTER SHAPE HAS BEEN CUT.
SA : 39.86mm2
SA : 7801mm2
SA : 156.93mm2
SA : 620mm2
SA : 538.78mm2
SA : 1583.24mm2
SA : 800.93mm2
SA OF BeO : 1977mm2
SA : 699.65mm2
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ATLAS FORWARD TRACKER
MIDDLE MODULE, BeO/AlN/TPG VERS.
NP27-03-120
DO NOT SCALE
FIRST ISSUE
MODIFICATIONS
THIRD ANGLE PROJECTION

Figure 5:

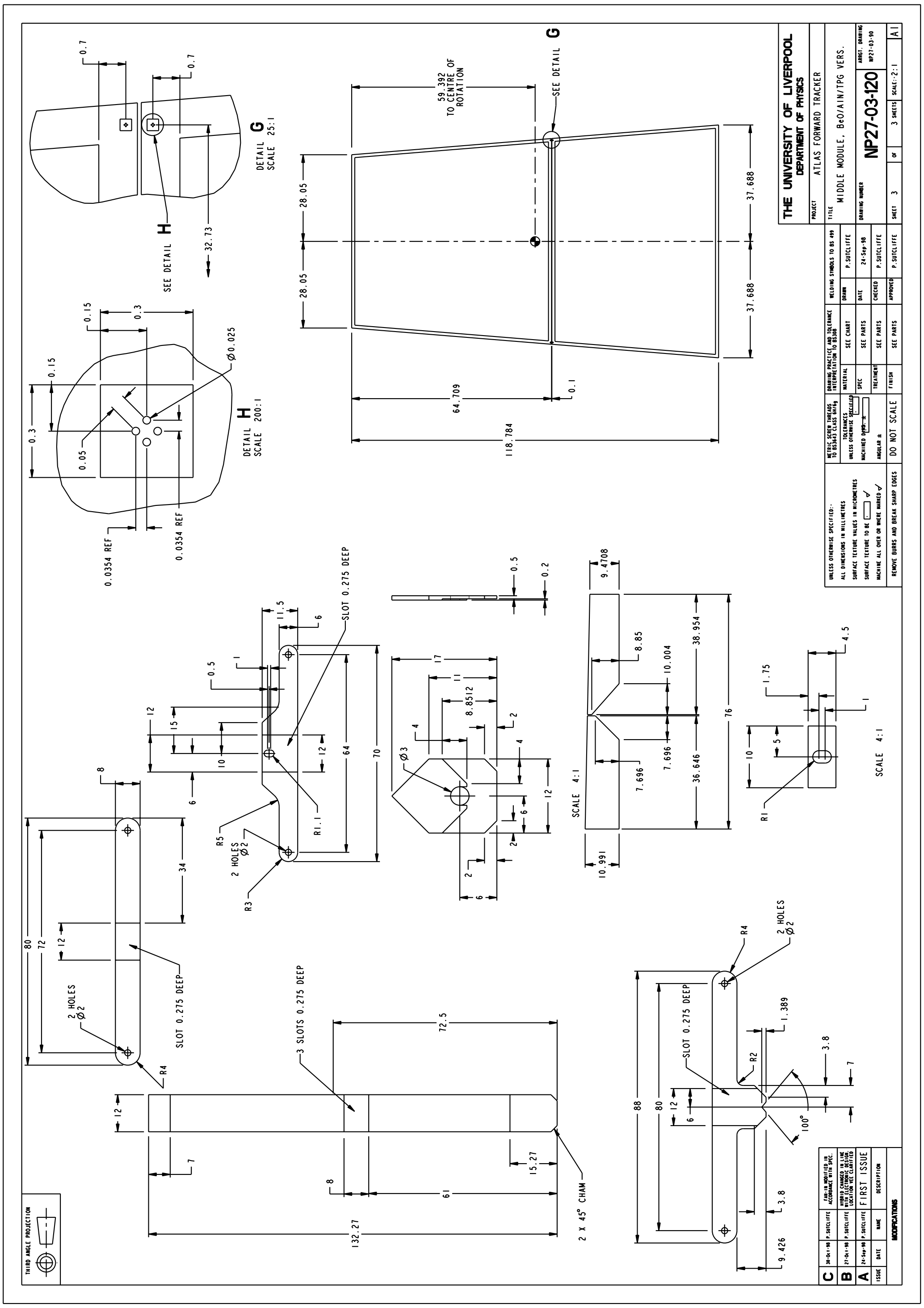

THE UNIVERSITY OF LIVERPOOL
DEPARTMENT OF PHYSICS
ATLAS FORWARD TRACKER
MIDDLE MODULE, BeO/AlN/TPG VERS.
NP27-03-120
DO NOT SCALE
THIRD ANGLE PROJECTION
MODIFICATIONS
FIRST ISSUE

Figure 6:

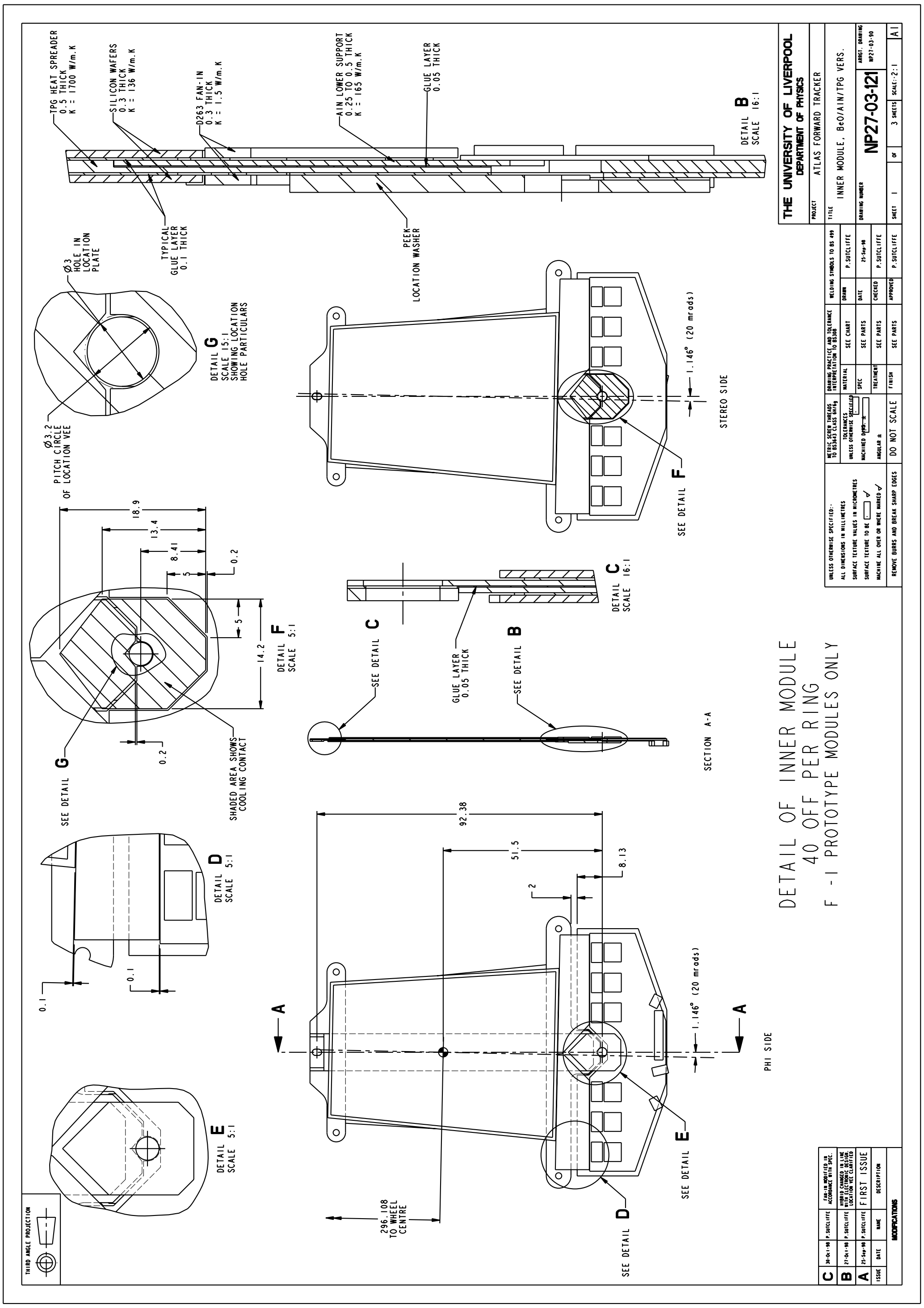
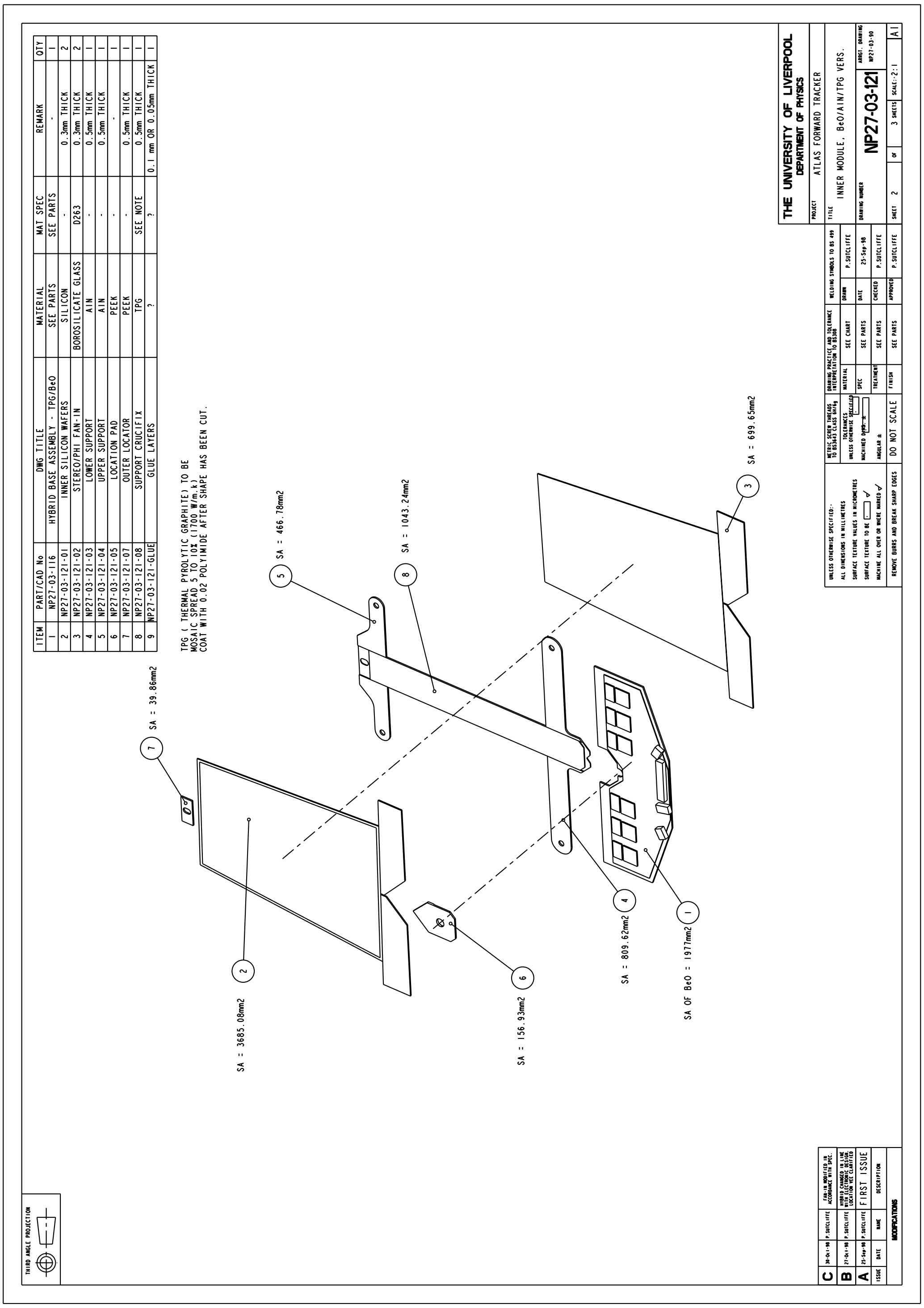

DETAIL OF INNER MODULE
40 OFF PER RING
F -1 PROTOTYPE MODULES ONLY
THE UNIVERSITY OF LIVERPOOL
DEPARTMENT OF PHYSICS
ATLAS FORWARD TRACKER
INNER MODULE, BeO/AlN/TPG VERS.
NP27-03-121
PHI SIDE
STEREO SIDE
SECTION A-A

Figure 7:



ITEM | PART/CAD No | DWG TITLE | MATERIAL | MAT SPEC | REMARK | QTY
1 | NP27-03-116 | HYBRID BASE ASSEMBLY - TPG/BeO | SEE PARTS | SEE PARTS | - | 1
2 | NP27-03-121-01 | INNER SILICON WAFERS | SILICON | - | 0.3mm THICK | 2
3 | NP27-03-121-02 | STEREO/PHI FAN-IN | BOROSILICATE GLASS | D263 | 0.3mm THICK | 2
4 | NP27-03-121-03 | LOWER SUPPORT | AlN | - | 0.5mm THICK | 1
5 | NP27-03-121-04 | UPPER SUPPORT | AlN | - | 0.5mm THICK | 1
6 | NP27-03-121-05 | LOCATION PAD | PEEK | - | - | 1
7 | NP27-03-121-07 | OUTER LOCATOR | PEEK | - | 0.5mm THICK | 1
8 | NP27-03-121-08 | SUPPORT CRUCIFIX | TPG | SEE NOTE | 0.5mm THICK | 1
9 | NP27-03-121-GLUE | GLUE LAYERS | ? | ? | 0.1 mm OR 0.05mm THICK | 1
TPG (THERMAL PYROLYTIC GRAPHITE) TO BE
MOSAIC SPREAD 5 TO 10% (1700 W/m.k)
COAT WITH 0.02 POLYIMIDE AFTER SHAPE HAS BEEN CUT.
SA = 39.86mm2
SA = 466.78mm2
SA = 1043.24mm2
SA = 699.65mm2
SA = 3685.08mm2
SA = 156.93mm2
SA = 809.62mm2
SA OF BeO = 1977mm2
THIRD ANGLE PROJECTION
THE UNIVERSITY OF LIVERPOOL
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ATLAS FORWARD TRACKER
INNER MODULE, BeO/AlN/TPG VERS.
NP27-03-121
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FIRST ISSUE
MODIFICATIONS

Figure 8:

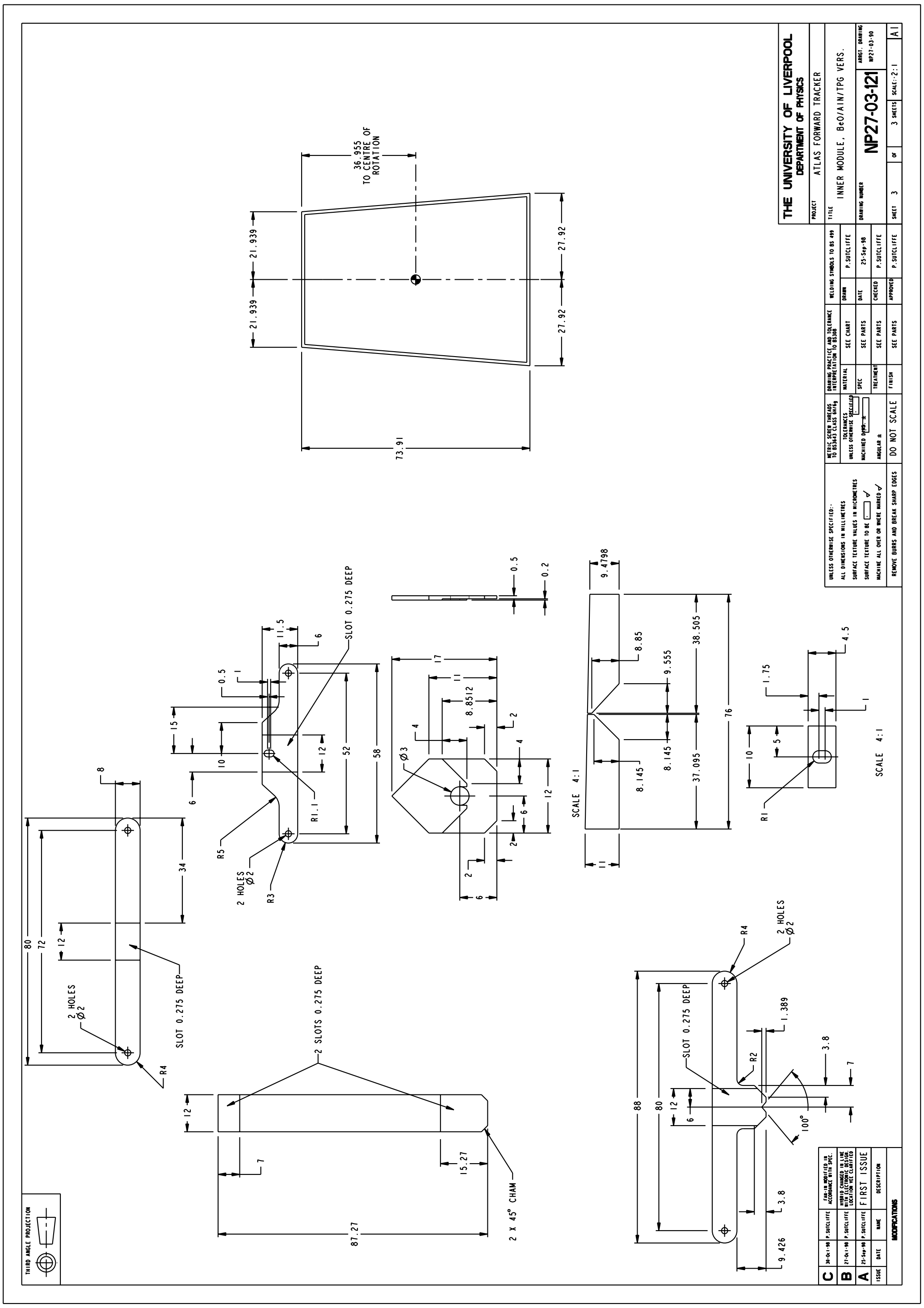
THE UNIVERSITY OF LIVERPOOL
DEPARTMENT OF PHYSICS
ATLAS FORWARD TRACKER
INNER MODULE. BeO/AlN/TPG VERS.
NP27-03-121
DO NOT SCALE
SCALE 4:1
FIRST ISSUE
MODIFICATIONS
THIRD ANGLE PROJECTION

Figure 9:

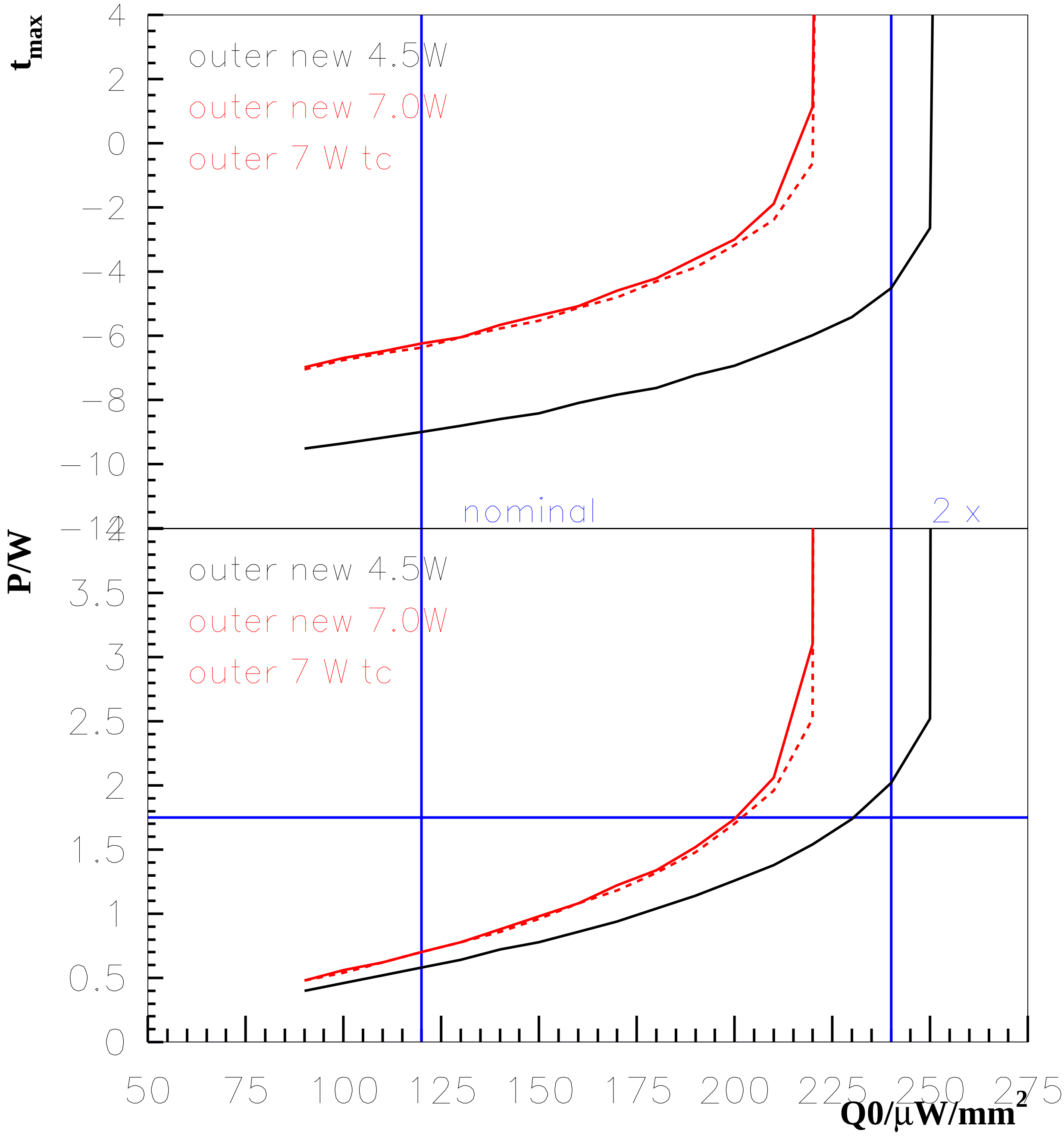

Figure 10: Thermal properties of outer module. (Top): Maximal temperature in the detectors as a function of the power density (normalized to 0^{o}C). (Bottom): Power produced in the detectors as a function of the power density. The vertical lines indicate the nominal power density and the safety factor. The horizontal line is the limit of the power supply (1.75 W). Solid line: 4.5 W hybrid power. Dashed line: 7W hybrid power. Coolant temperature at -15^{o}C

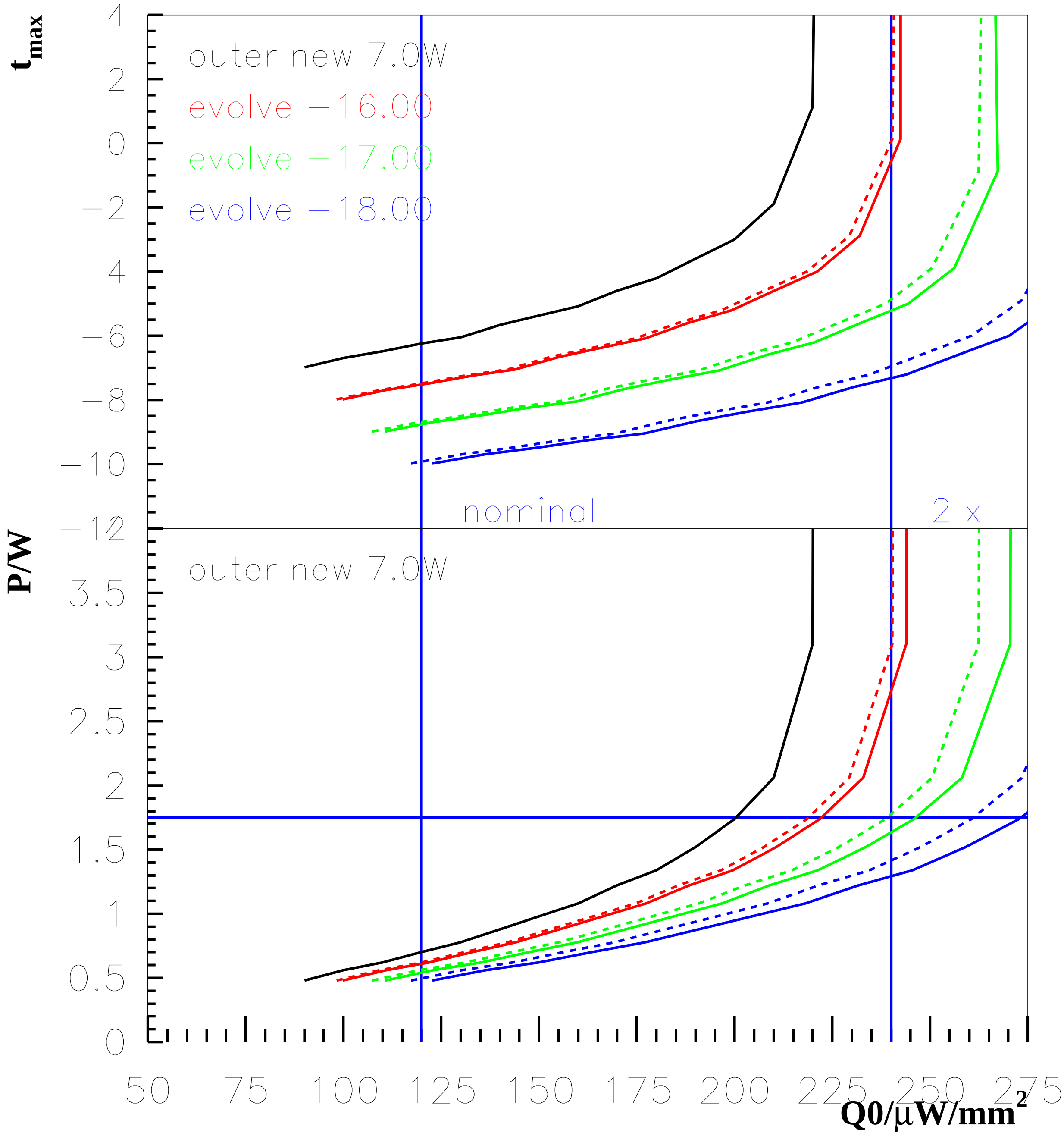

Figure 11: Maximum temperature in the detectors and total power produced for various coolant temperatures for 7W hybrid power (Outer module). These curves are derived from the full simulation at -15^{o}C using a scaling law. The dashed lines indicate the uncertainties of this scaling.

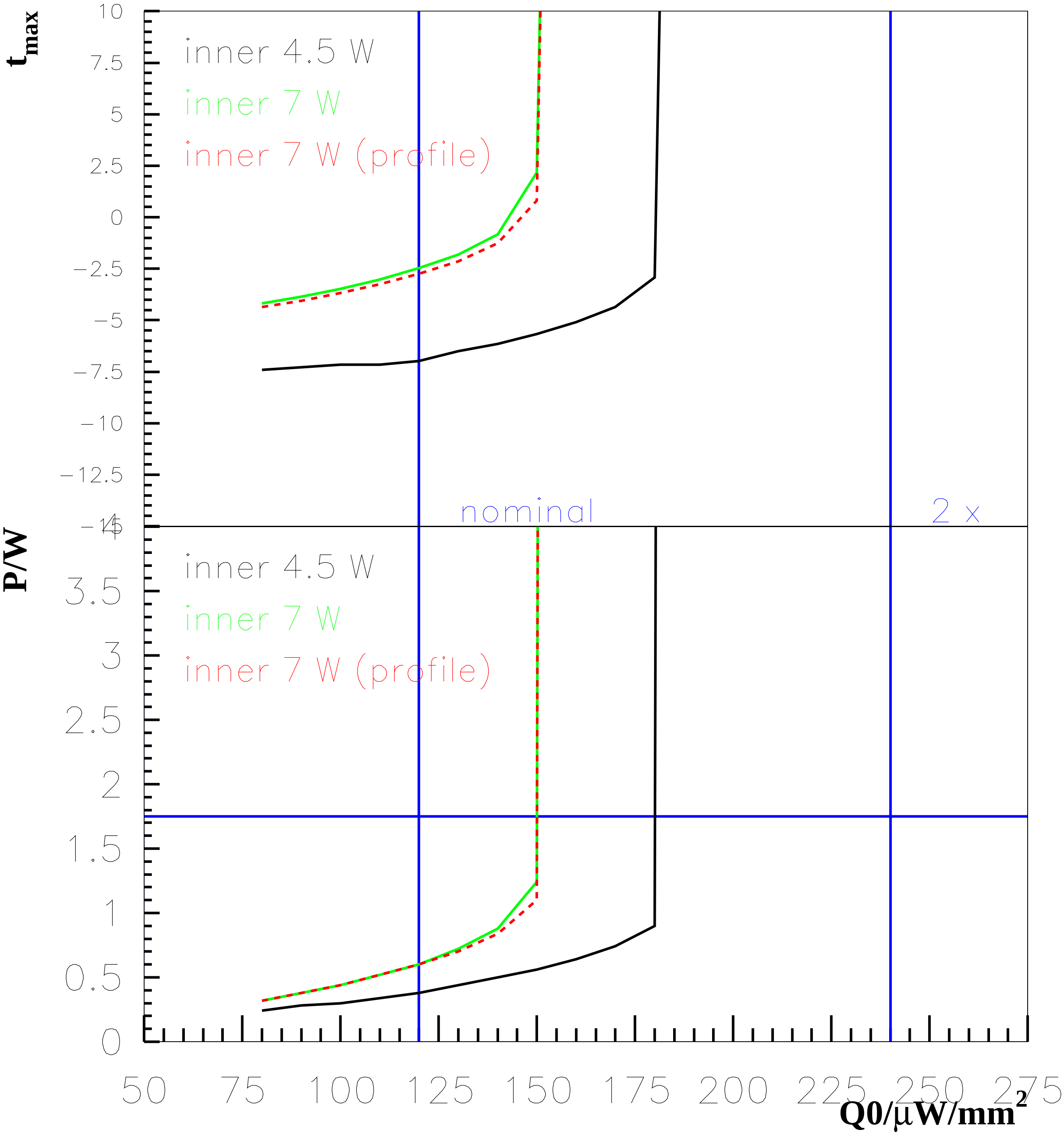

Figure 12: Thermal properties of inner module. (Top): Maximal temperature in the detectors as a function of the power density (normalized to 0^{o}C). (Bottom): Power produced in silicon as a function of the power density. The vertical lines indicate the nominal power density and the safety factor. The horizontal line the limit of the power supply (1.75 W). Solid line: 4.5 W hybrid power. Dashed line: 7W hybrid power. Coolant temperature at -15^{o}C

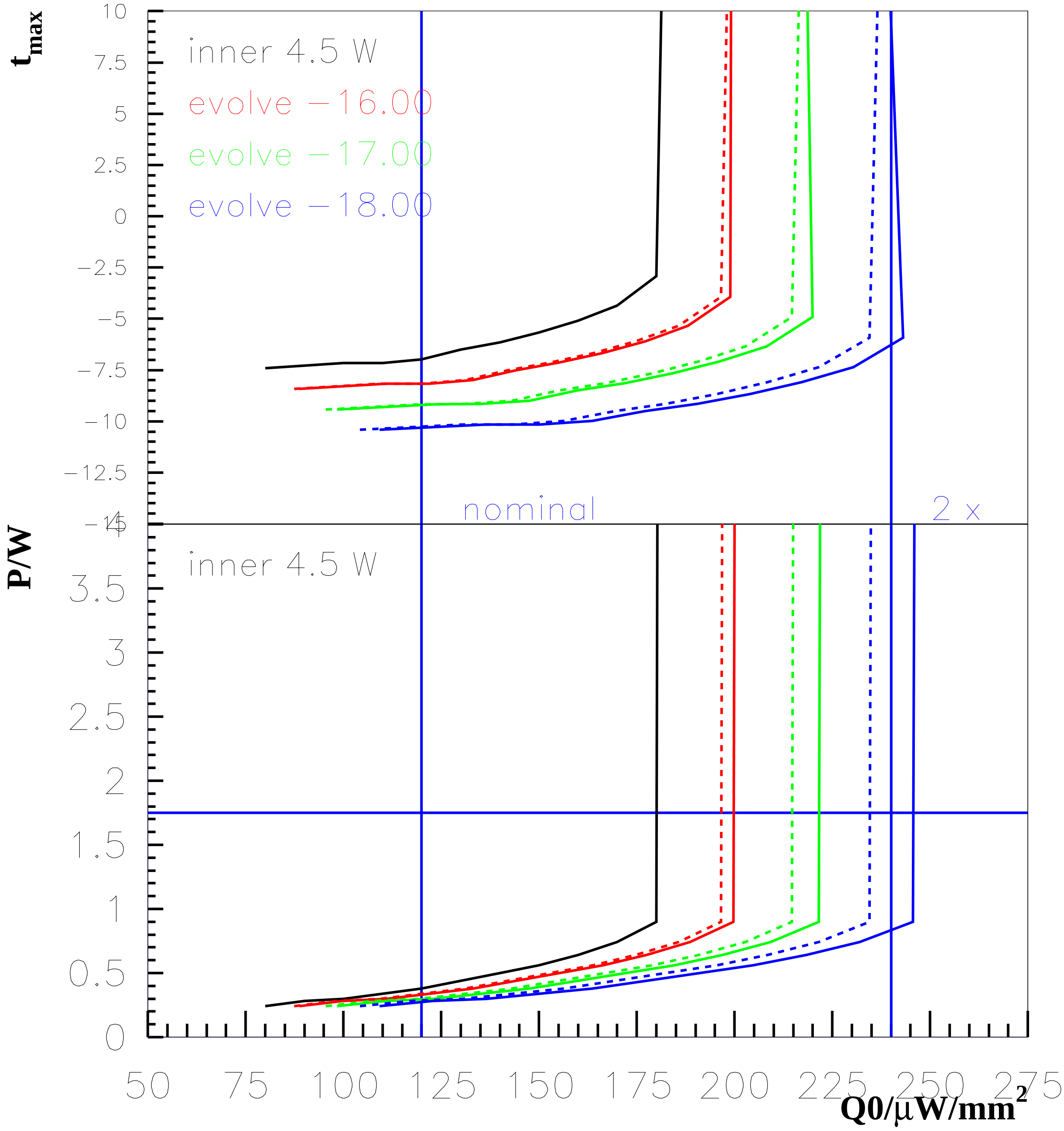

Figure 13: Maximum temperature in the detectors and total power produced for various coolant temperatures for 4.5W hybrid power (inner module).

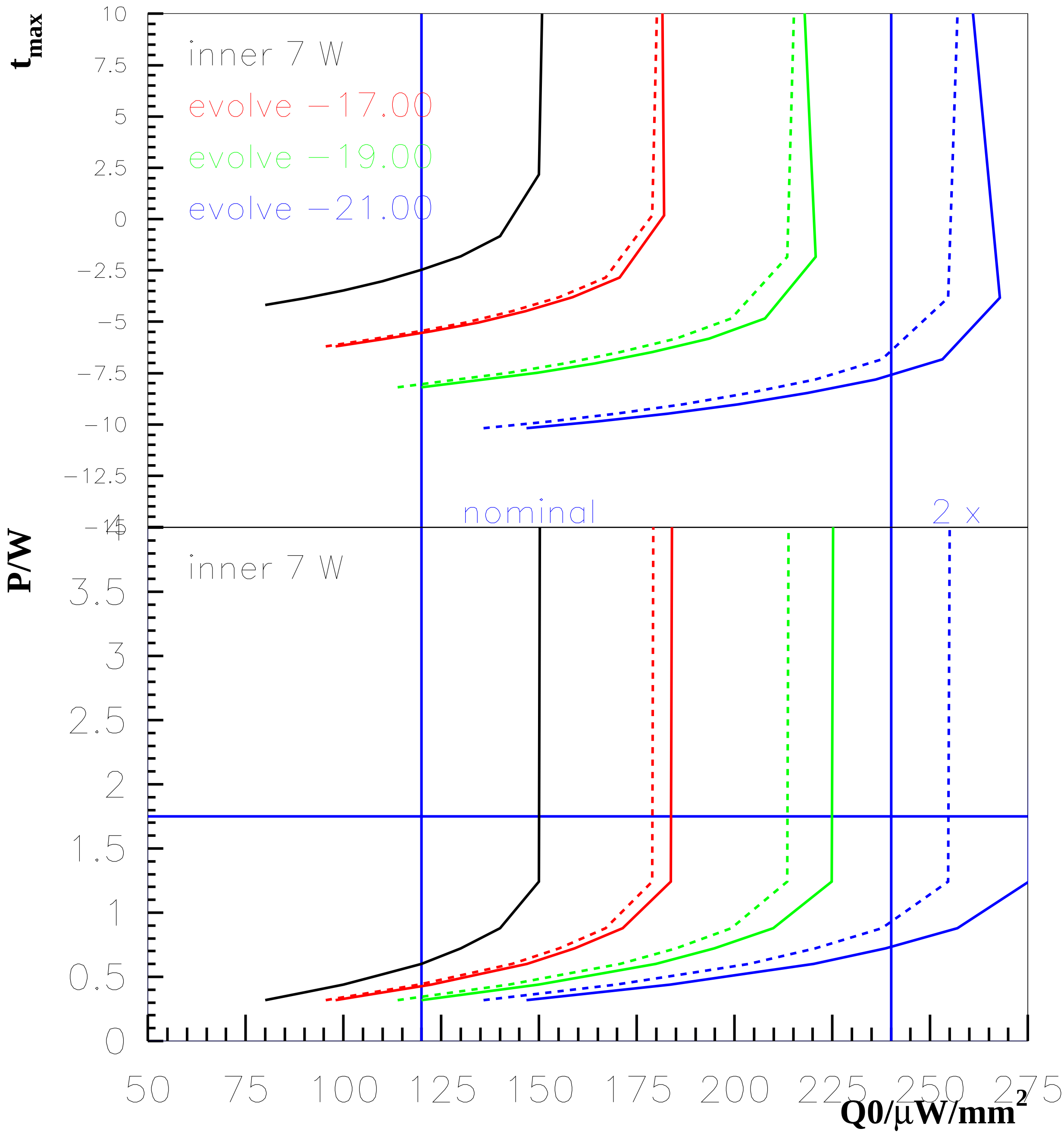

Figure 14: Maximum temperature in the detectors and total power produced for various coolant temperatures for 7W hybrid power (inner module).

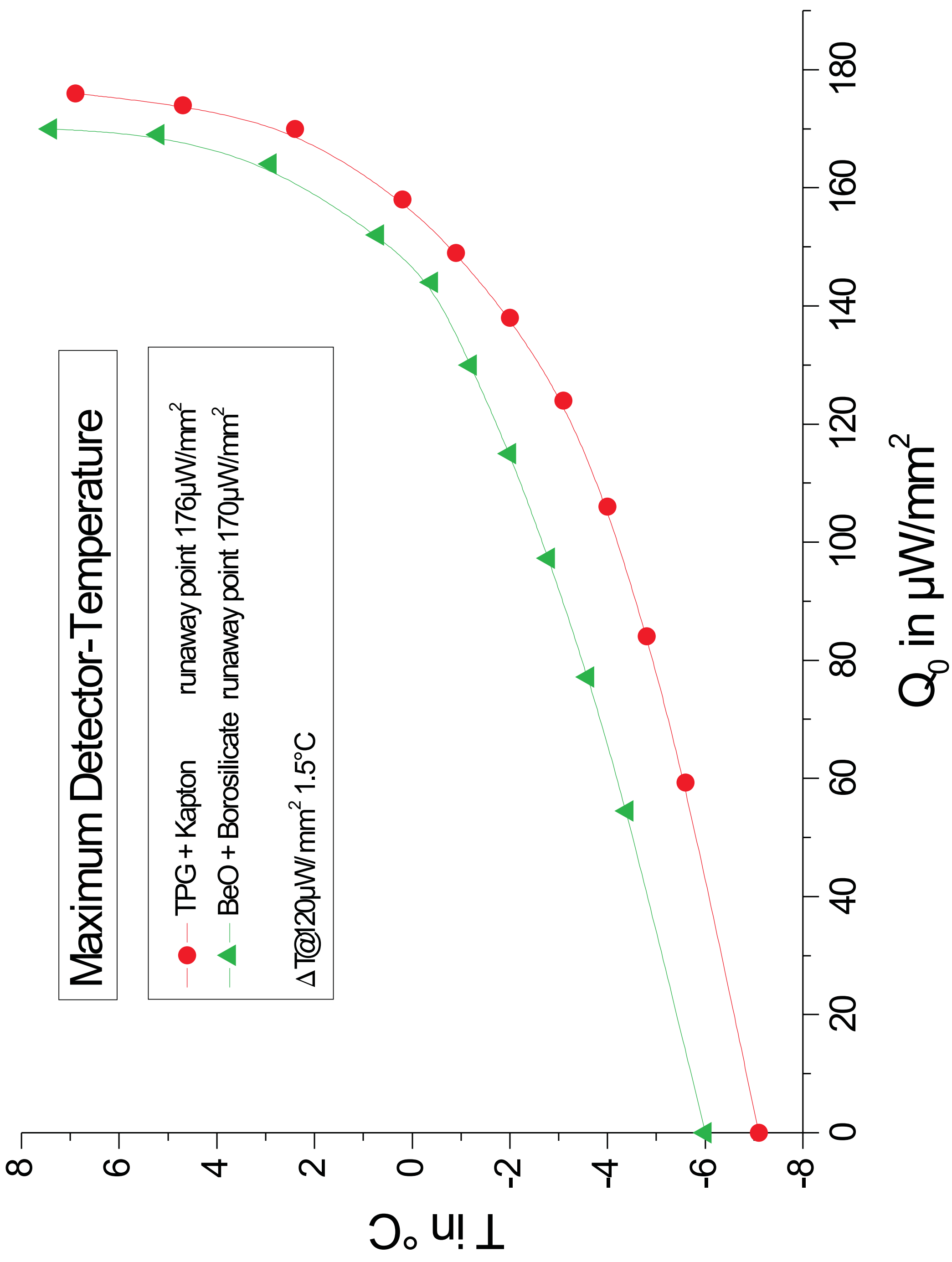

Figure 15: Thermal performance of outer module with BeO and TPG hybrid.