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The Compact Muon Solenoid Experiment

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ASSEMBLY OF A CLOSED MODULE OF 4 MSGC FOR THE CMS FORWARD TRACKER

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Abstract

The design of a MSGC module with a single gas volume and with the read-out electronics outside, allows a clean and fast assembly. It is well adapted to the large number of units which must be produced for the CMS forward tracker. Two prototypes of 4 substrates were realized for the CMS MF1 milestone. Their components and assembly are described here. The performance measured in a test beam is discussed in another note.

Summary :

1 Module design

1.1 Cleanness constraint

It is established that the performance and lifetime of the MSGC detectors strongly depend on the cleanness achieved at their assembly. We decided therefore, for the MF1 project, to build modules where the gas volume is enclosed on the substrates before the connection to the read-out electronics. It is the best choice to reduce the number of pieces introduced into the gas volume and to decrease the number of manipulations of the substrates from the cleaning to the gas enclosure. The free access to the connections, at the level of the read-out and of the high voltage, is a further advantage to remove a failing hybrid or a short circuit that can occur in a completed module.

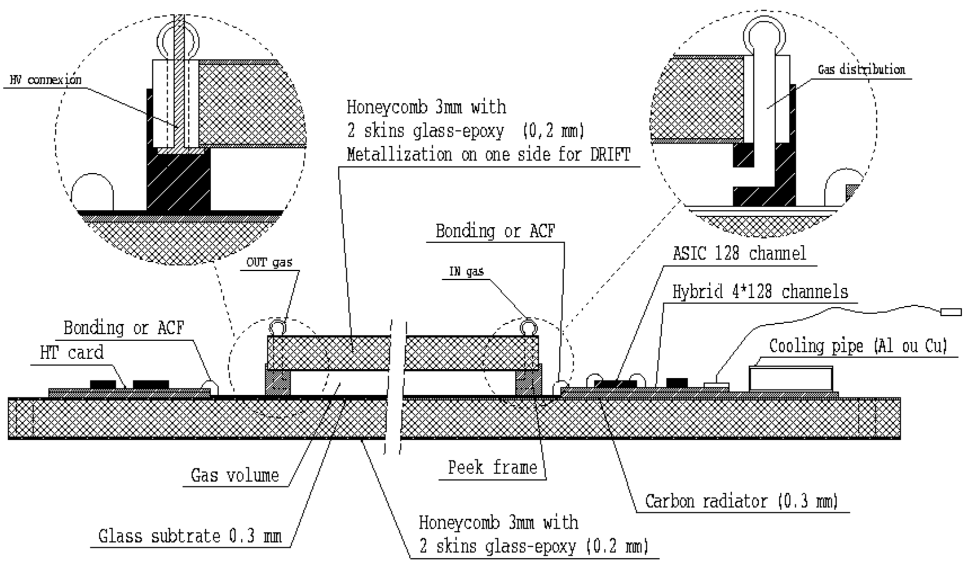
1.2 Assembly constraint

The simplicity of assembly is a second important parameter to lower the fabrication cost and delay. Regarding this aspect, the proposed design is satisfactory since the preparation of pieces, the mechanical assembly and the connection of the hybrids can be performed in parallel on different modules. We opted for a structure with a single gas volume and a single drift electrode, to reduce the number of mechanical elements and simplify the mounting.
The gas thightness is ensured by gluing most of the components, so that only the pieces outside the gas volume can be recovered in case of a failure. A good production yield can be reached under two conditions : if the quality of the mounted substrates is ensured, if the assembly procedure does not introduce damages. The first condition can be fulfilled by a high voltage test of the substrates before mounting. The production of pre-series will allow to determine the yield of good substrates and to decide between a systematic or a sampling test. The second condition is more likely to be satisfied with a small number of manipulations as in the proposed design. No damages appeared related to the mounting procedure in the 2 modules realized. A larger experience with dummy prototypes should nevertheless allow to check and improve the assembly scheme. To limit the loss of supplied materials in the inevitable case of failure, a number of 4 substrates per module was decided. A further advantage of this choice is the compatibility of the module length with the currently available mounting equipments. A carefull design of the gas frames will allow to limit to 1.5% the dead area between two modules.

1.3 Module scheme

The module scheme is shown in figure 1. The main features are the following :
- the 4 substrates are glued on a honeycomb structure,
- the gas frame is glued on the 4 substrates,
- the drift electrode is a metallized honeycomb structure glued on the gas frame.

A simulation shows that the module can resist the atmospheric pressure ± 5 mbar without significant deformation. The number of radiation length is 0.92 % (the two honeycomb structures, with glass fibre skins, contribute only to an equivalent thickness of about 550 μm of glass). The details of the components and of the assembly are described in the rest of this document.



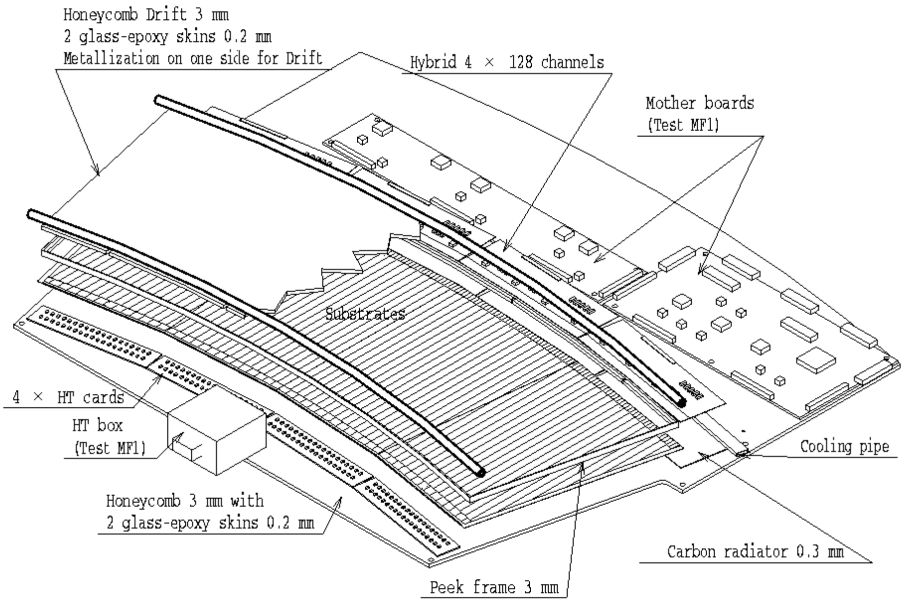


Figure 1

2 Components

2.1 Honeycomb structures

The module basis and the drift electrode are each made of a honeycomb structure, 3 mm thick. The core is made of NOMEX (aramide) and the skins, 0.2 mm thick, are made of 2 layers of glass fibres stratified in epoxy. The study of the thermal constraints will allow to determine if carbon fibre skins could be used.

2.1.1 Module basis

The module basis is the support on which the MSGC substrates are glued. The exemple of the MF1 module basis is shown on figure 2. The tooling was done with a CNC machine. The tapped holes, for the positioning of the modules in the support structure, are made of PEEK inserts glued in the honeycomb structure with fast araldite.

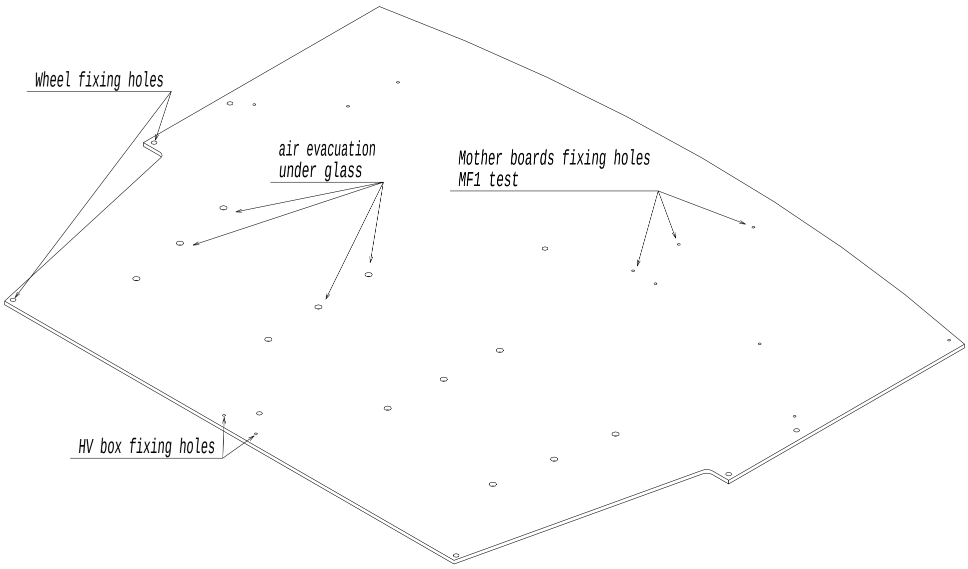


Figure 2

2.1.2 Drift electrode

To produce the drift electrode, the honeycomb structure was metallized. For the MF1 prototypes, a coating of 1.2 μm Cu plus 1.2 μm Ni was performed directly on the glass-epoxy skin. The deposition will be improved with a slight polishing of the honeycomb skin. The connection to the high voltage outside the gas volume was achieved throw the honeycomb structure with a conductive pin located at the edge where it is glued on the gas frame. To increase the electrical insulation and to reduce the gas porosity, the outer skin of the honeycomb can be varnished.

2.2 MSGC Substrates

The substrates produced by Optimask are 0.3 mm thick glasses with a wedge shape pattern of strips. The length is 180 mm and the larger width is 120 mm.

2.3 Gas frame and pipes

The gas frame and pipes are made of Peek (fig. 3). The gas frame was milled with the CNC machine and drilled for gas inlets and outlets. A moulding process can be foreseen for a large scale production.

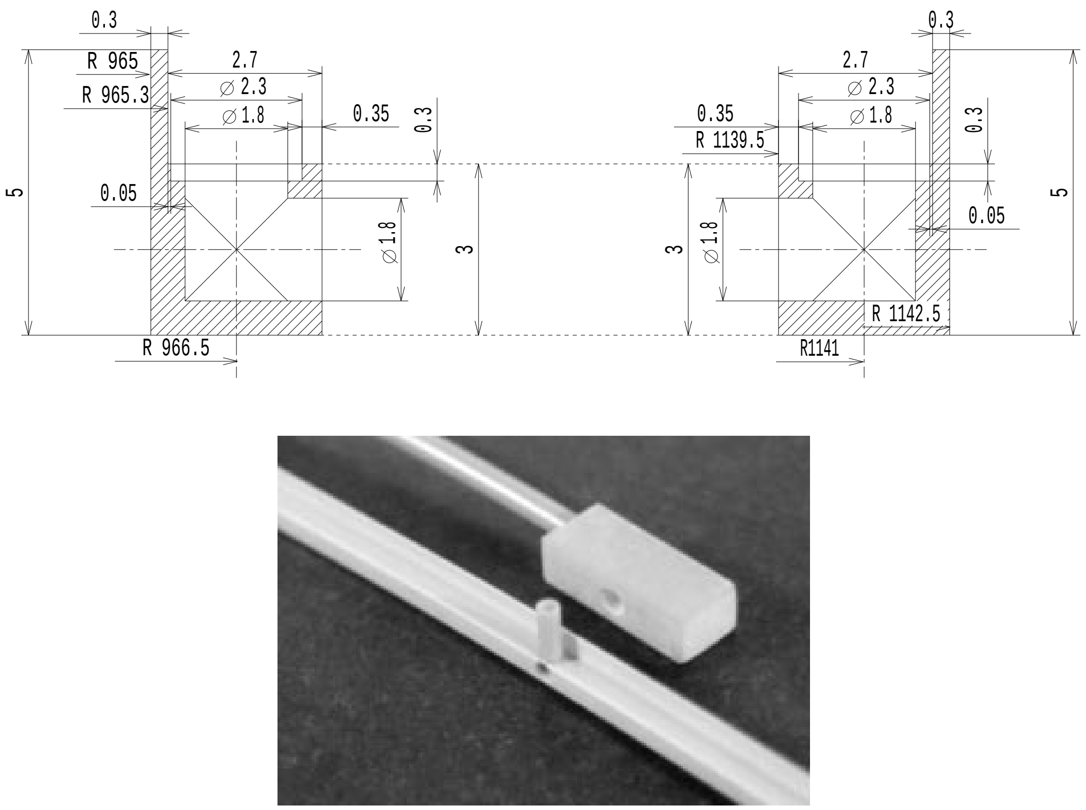


Figure 3

2.4 Cooling

Although it has not been tested, the water cooling of the read-out hybrids was implemented in the MF1 modules. It consists of thermal conductors of carbon fibres glued below the hybrids on one side and below a cooling pipe on the other side. A silicon glue was used to allow the dismounting of these carbon radiators. In a final module, it could be replaced by an epoxy glue of better thermal conductivity.

2.5 Covers and high voltage connection

Two covers were used to protect the wire bondings between substrates and hybrids. On the read-out side, the cover is also the light shielding of the front end chip. The connections of the high voltage to the drift electrode and to the four substrates were done through a distribution box fixed on the module basis.

3 Assembly procedure

3.1 Cleaning

The mechanical pieces (honeycomb, gas frame and gas inlets) are cleaned with propanol-2 and dried with nitrogen. The cleaning of the substrates is done in an ultra-sound bath equipement, first with propanol-2 and then with deionized water (18 MΩ). The substrates are dried with nitrogen.

3.2 Positioning

The positioning of the substrates on the module basis is one thorough part of the assembly. Crosses on the substrates should be aligned with a $\pm$ 10 μm accuracy with respect to the inserts of the module basis. An optical bench allowing the 2D-displacement of a binocular with an optical reticle was chosen to perform this operation (fig. 4). The rules of the bench can be driven by a PC so as to place the reticle at the theoretical positions of the substrate crosses. To decouple the gluing of the module basis from the positioning, the 4 substrates are aligned on an intermediate jig (fig. 5). The sequence of operations is the following :

1. Alignment of the jig and of the microscope :
Two reticles on the jig allows to position it parallel to the X-axis of the bench. The central reticle is then taken as the reference for the microscope.

2. Positioning of each substrate :
- The substrate is pre-positionned active face down on the jig with an accuracy of 100 μm. The substrate is laid on the jig at the level of the connection pads and at 4 places on the edges. The contacts are therefore made outside the active area with an intermediate Teflon foil to avoid scratches when moving the substrates.
- the binocular is displaced to the theoretical position of the first cross on the substrate which is aligned by hand to the binocular reticle. The same procedure is then applied with a second cross and iterated until the required accuracy is reached on both crosses. A mean number of 5 iterations are needed to position a substrate.
- The final position is preserved by suction of the substrate through 4 holes in the supporting jig.

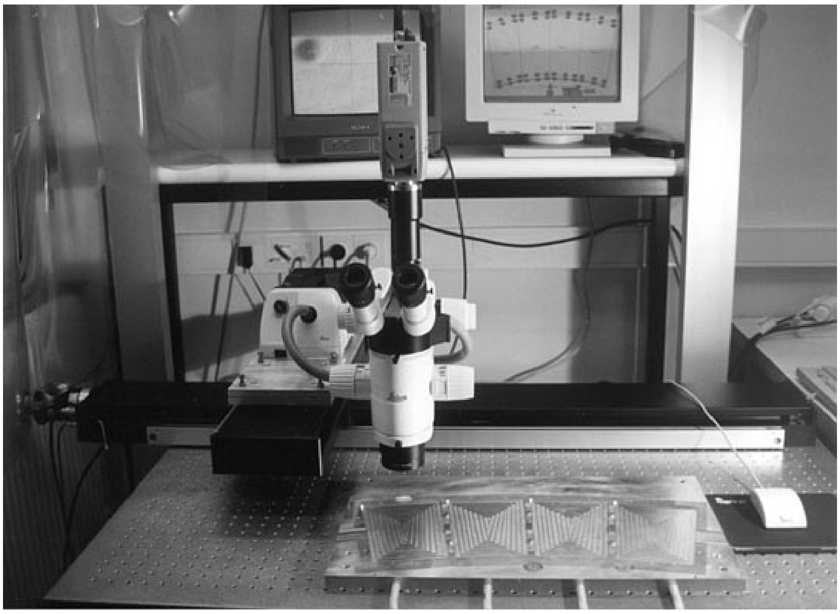


Figure 4

3.3 Gluing of the module basis

The glue is deposited using a calibrated squirt defining the thickness of the line. The trajectory and the pressure are controlled by a PC (fig. 5). The honeycomb structure is then pressed against the glass, guided by pins located on the jig at the place where the module will be positionned in the final support wheel. 4 weights of 4 kg are used to spread the glue. The polymerisation is done at room temperature.

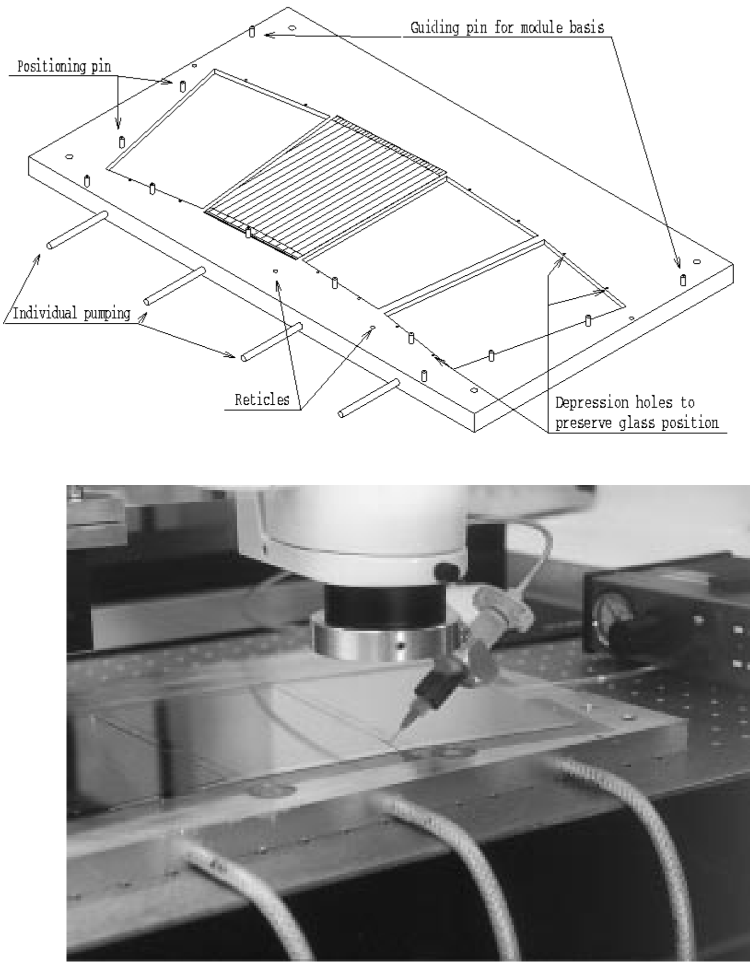


Figure 5

3.4 Gas enclosure

The gas pipes and the honeycomb drift electrode are glued to the gas frame at room temperature. This unit is then glued on the substrates with a position accuracy of $\pm$ 0.1 mm. At this stage the gas pipes can be temporarly sealed and the module can be removed from the clean area. Different studies are in progress to improve the gluing of Peek on glass, a chemical treatment of the PEEK surface or a different geometry of the frame are foreseen.

3.5 Mounting and connection of hybrids

The hybrids are glued on the honeycomb basis under a binocular to align the bonding pads. The carbon radiator for cooling is glued to the back of the hybrid. The connexion is done by wedge bonding using a 15 μm aluminium wire.

3.6 Final assembly

The final assembly involves the following operations :
- gluing of the gas pipes,
- gluing of the cooling pipe,
- installation of covers,
- installation of HV distributor,
- installation and connection of read-out control cards.

4 Production Management

4.1 Production time

The manpower time for each operation involved in the assembly of a module is summarized in table 1 : it includes neither the cutting and test of the substrates nor the final test of the module. The management of tasks is extrapolated to a large production in a Gantt diagram (fig. 6). As compared to table 1, a 30 % contingency time was assumed for each operation and it is assumed that the gas frame will be moulded. A single production line will basically do for the production of 2 tested modules per day with a team of 6 technicians and a management engineer. A further manpower will be needed for the substrates preparation (cutting and/or test) and the test of the completed modules.

		fab. time (mn)	gluing time (h)
Preparation of pieces	Honeycomb basis	90	12
	Drift plan	30	
	gas frame inlets outlets	75	24
	Covers, pipe, carbon	150	
	Gluing gas frime - drift plan	60	24
Positioning of substrates	Optical inspection+cleaning	80	
	Alignment	60	
	Gluing on basis	30	24
Gluing gas frame - honeycomb basis leak test		120	24
Connection		270	

Table 1

4.2 Prototyping cost

The cost of raw materials for the prototypes was about 1500 CHF not including the substrates. It is dominated by the price of the honeycomb structures and of the drift metallization. At the production stage, their cost, according to the present suppliers, will be significantly reduced. The knowledge of costs is summarized in table 2. A further reduction can be expected using moulded Peek frames.

	Materiel	Prototyping cost/Production cost (CHF)
Cleaning	Solvants, paper, glaves	30
Module basis	Honeycomb basis	575/65
Drift plan	Honeycomb basis	250/38
	Metallization	375/40
Gas frame and pipes	PEEK	195
Carbon radiator	K-1100 2K	25
Cooling pipe, covers	Copper	38
Glue	EPO 93L, Elecolit, Silicomet	20
	Total	1 508/451

Table 2

5 Conclusion

The prototyping of two modules of 4 MSGC substrates has proven the merit of a design with a single gas volume and the read-out electronics outside the active area. The number of pieces and the number of operations involved in the assembly are less than in the other modules realized for the MF1 milestone. The experience with the 2 MF1 protoypes indicates that one line of equipments can handle the production of two modules per day with a team of 6 people including a superviser. two additional people at least will be needed to prepare the substrates and test the completed modules. In the CMS V4 forward tracker layout, the number of substrates is 7264 divided in 1816 modules. To produce this quantity two sets of equipments and two teams will be needed for 2.5 years.

Nº	Nom de la tâche	Durée
1	Module 1	4,08j
2	Preparation of pieces	2j
3	Module base	115m
4	Polymerisation	12h
5	Drift electrode	40m
6	Gas frame and inlets	10m
7	Polymerisation	24h
8	Covers,pipes,carbon	200m
9	Gluing frame-drift	80m
10	Polymerisation	24h
11	Positioning	1,47j
12	Inspection+cleaning	105m
13	Substrates alignment	80m
14	Base gluing	40m
15	Polymerisation	24h
16	Gluing frame-base	160m
17	Polymerisation	24h
18	Hybrids gluing	40m
19	Polymerisation	24h
20	Connection	240m
21	Module 2	4,16j
22	Preparation of pieces	1,92j
23	Module base	115m
24	Polymerisation	12h
25	Drift electrode	40m
26	Gas frame and inlets	10m
27	Polymerisation	24h
28	Covers,pipes,carbon	200m
29	Gluing frame-drift	80m
30	Polymerisation	24h
31	Positioning	1,58j
32	Inspection+cleaning	105m
33	Substrates alignment	80m
34	Base gluing	40m
35	Polymerisation	24h
36	Gluing frame-base	160m
37	Polymerisation	24h
38	Hybrids gluing	40m
39	Polymerisation	24h
40	Connection	240m

Annexe : Positioning performance

The positioning accuracy was checked on the optical bench after the gas enclosure of the module. A substrate position is measured with two crosses located outside the gas frame. The results are summarized in table 3.

Module 1

The substrates were positionned (face down) from left (4) to right (1). The theoretical values used for the position of the crosses on the substrates were wrong, leading to the large error on the positioning of the first substrate (4). The limited accuracy of the glass cutting induced an additional shift of 16 μm of substrate 3 as compared to 4. These defects have affected the positioning of the later substrates. A global shift towards the bottom was also observed from right to left. This effect is due to a parallax problem when focusing on the different crosses. It can be avoided with a smaller magnification or increasing the field depth of the binocular.

Module 2

Taking advantage of the experience gained with the first module, the positioning was done with a smaller magnification (x100) and in the following order of the wafer number : 3,4,2,1. The 5 μm accuracy on the position of the first substrate is within the global $\pm$ 8 μm precision expected at constant temperature (the bench accuracy was checked to $\pm$ 3 μm and the width of the crosses is 5 μm). The positioning of further substrates at 54 μm of each others is more delicate and led to a smaller accuracy with substrate 4. In case of substrates 2 and 1, the accuracy was dominated by the poor precision on the glass cutting.

Module 1		Measurement				Theoretical position	
Substrates	Points	X	DX	Y	DY	X	Y
1	A	- 191,436	- 0,003	192,651	-0,071	-191,439	192,580
	E	-161,013	0,028	13,234	-0,088	-160,985	13,146
2	B	- 64,078	-0,001	206,950	-0,035	-64,081	206,915
	F	-53,933	0,046	25,256	-0,056	-53,887	25,200
3	c	64,076	0,005	206,931	-0,016	64,081	206,915
	G	53,842	0,045	25,242	-0,042	53,887	25,200
4	D	191,419	0,020	192,566	0,014	191,439	192,580
	H	160,923	0,062	13,163	-0,017	160,985	13,146
Module 2		Measurement				Theoretical position	
Substrates	Points	X	DX	Y	DY	X	Y
1	A	- 191,383	- 0,056	192,645	-0,065	-191,439	192,580
	E	-161,008	0,023	13,198	-0,052	-160,985	13,146
2	B	- 64,052	-0,029	206,932	-0,017	-64,081	206,915
	F	-53,875	0,012	25,219	-0,019	-53,887	25,200
3	c	64,080	0,001	206,910	-0,005	64,081	206,915
	G	53,889	0,002	25,196	-0,004	53,887	25,200
4	D	191,420	0,019	192,573	0,007	191,439	192,580
	H	160,984	0,001	13,137	-0,009	160,985	13,146

Table 3

Improvements and overall accuracy

The optical device can be improved by increasing the field depth and by reducing the vibrations with a stiffer support of the binocular. The manipulation of the substrates can be simplified holding them on the back side by a low pressure system, coupled with a positioning tool using eccentrics.

The expected accuracy of a substrate position with respect to the support wheel should be within $\pm$ 30 μm at constant temperature. This value results from : $\pm$ 8 μm of precision in the substrate to origin positioning, $\pm$ 10 μm for the origin to fixation holes distance and $\pm$ 10 μm for the module to wheel positioning (fig. 7). With the present materials, a tempretaure variation of 1^0 will lead to an 8 μm change of the module length, a negligible contribution to the final accuracy.

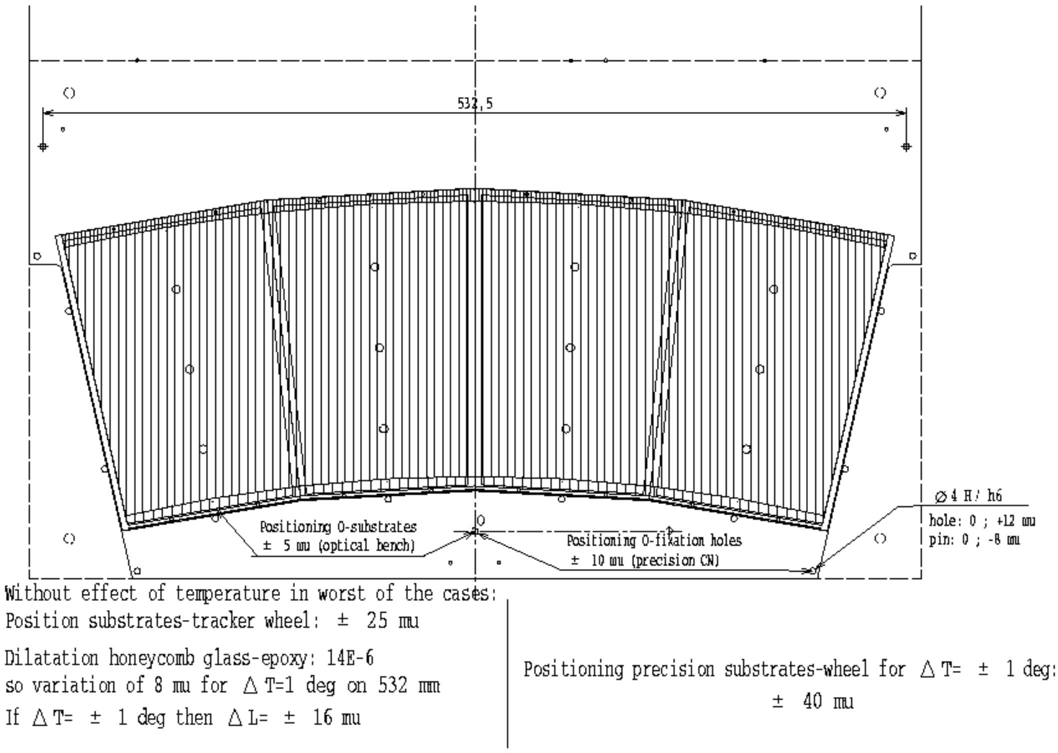

532,5
Positioning O-substrates
± 5 mu (optical bench)
Positioning O-fixation holes
± 10 mu (precision CN)
∅4 H/ h6
hole: 0 ; +12 mu
pin: 0 ; -8 mu
Without effect of temperature in worst of the cases:
Position substrates-tracker wheel: ± 25 mu
Dilatation honeycomb glass-epoxy: 14E-6
so variation of 8 mu for △T=1 deg on 532 mm
If △T= ± 1 deg then △L= ± 16 mu
Positioning precision substrates-wheel for △T= ± 1 deg:
± 40 mu

Figure 7