CERN-EP/TA1

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TECHNICAL NOTE

TA1/00-03

CONSTRUCTION OF GEM DETECTORS FOR THE COMPASS EXPERIMENT

Production Guide

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This document describes in detail the infrastructure, materials, procedures and quality requirements to build Triple-GEM detectors for the small area tracker system of the Compass experiment.

OUTLINE

1. INFRASTRUCTURE, MATERIALS AND TOOLS

1.1 INFRASTRUCTURE

The assembly of the GEM detectors is entirely carried out in a clean room[1]; it is a clean procedure and protective clothing is always worn. Fig. 1 shows a schematic view of the room and the main equipment. A custom-made, precise template is used to assemble the chamber, complemented with a simple gluing tool, as shown in Fig. 2. The different elements of the assembly are positioned with the help of precise pins, and kept in place with vacuum. The template is closed, flushed with clean nitrogen and heated up to 35 ^{o}C to avoid concentration of vapors and speed up glue polymerization respectively.
HV tests are done placing the assembly, at different steps of the construction, inside a clean Plexiglas box (Fig. 3) with as many HV feedthroughs as HV connecting pads the GEM has. The box is flushed with dry gas, nitrogen, to reduce moisture level. The HV power supply is a CAEN NIM module N471, with nA sensitivity.

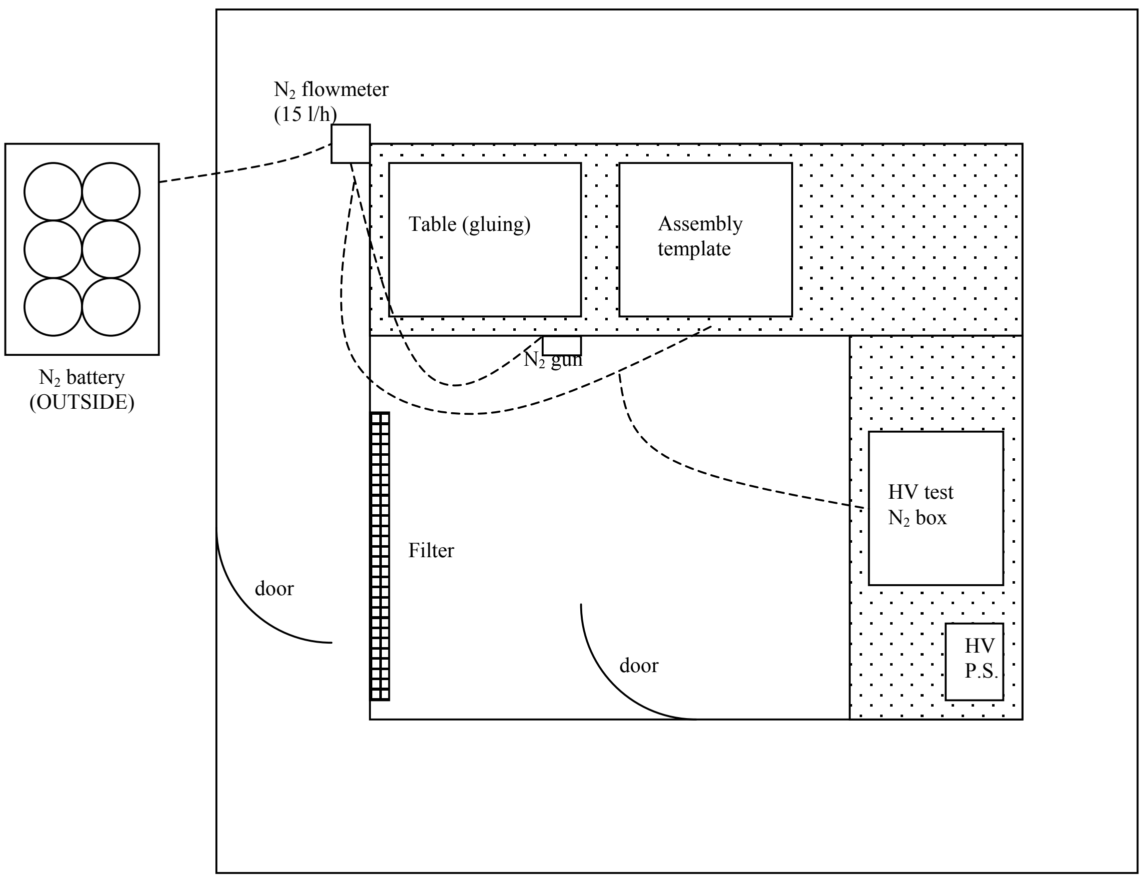

Fig. 1 Schematic view of the clean room where the Compass detectors are assembled.

[1] CERN/EP/TA1

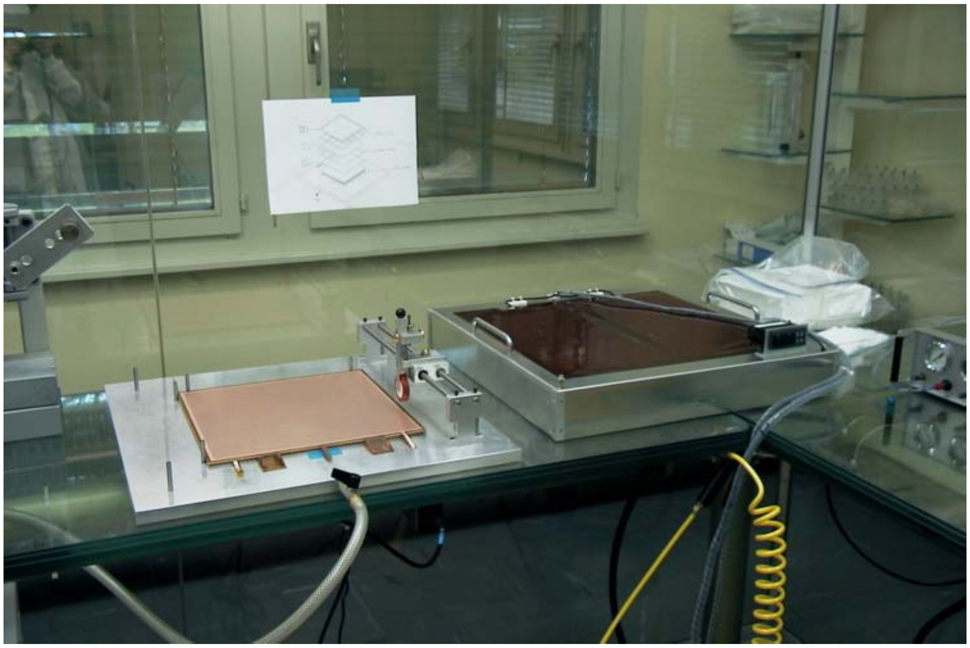

Fig. 2 Mounting template and gluing wheel used for the construction of GEM detectors.

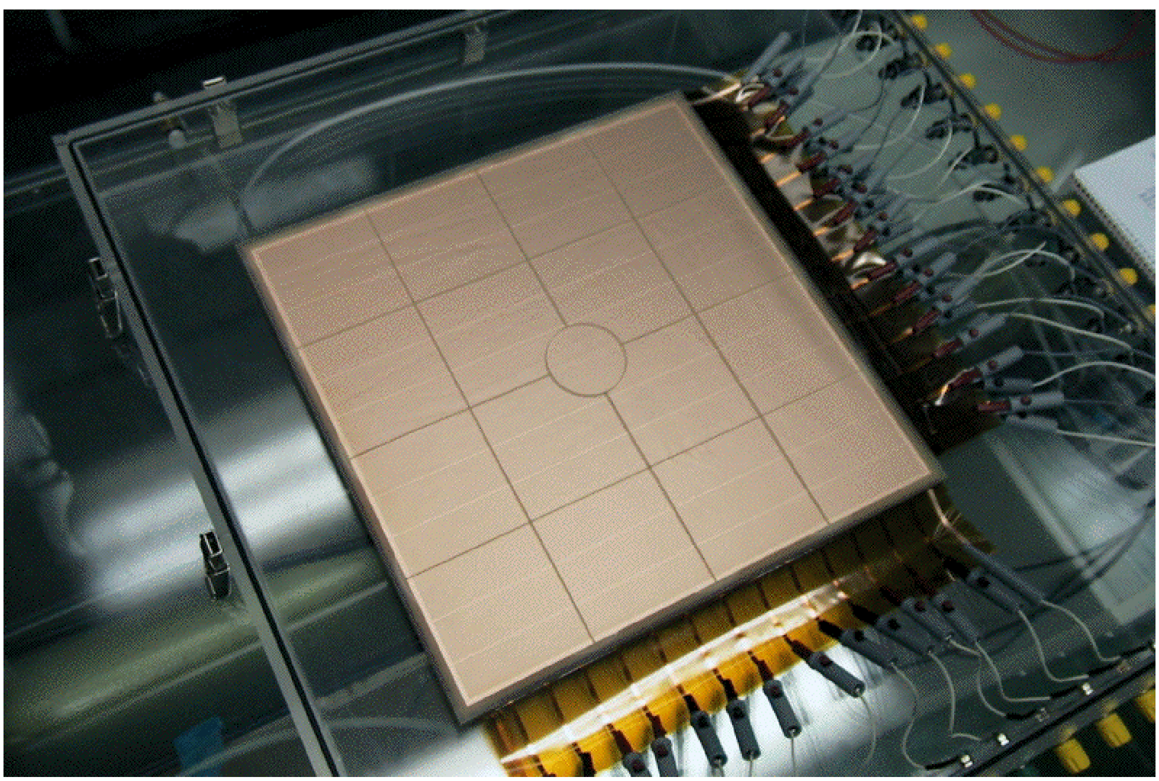

Fig. 3 GEMs are HV tested in a nitrogen box before being mounted in the detectors and during the assembly process.

1.2 ASSEMBLY MATERIALS

Fig. 4 shows an exploded view of the triple-GEM detector for Compass. Table 1 specifies the materials used in the assembly and Table 2 shows the material budget of the active area in a triple-Gem.

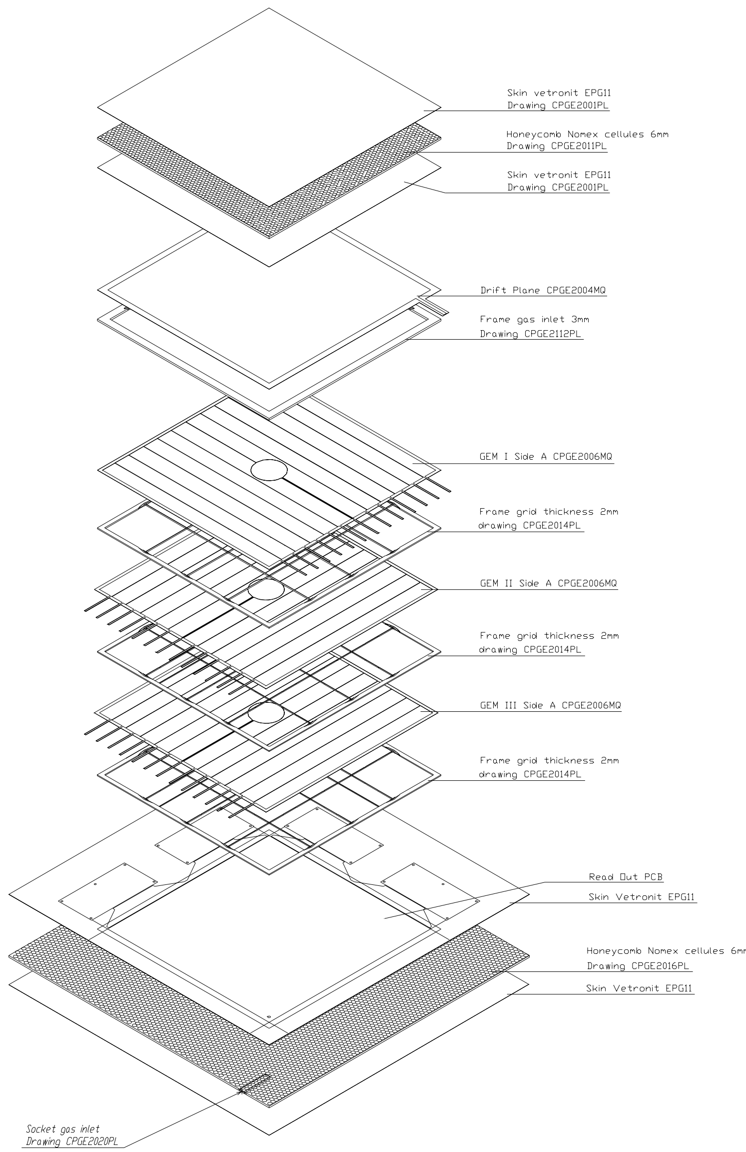

Fig. 4 shows an exploded view of the triple-GEM detector for Compass.

Material	Details	Supplied or manufactured by
Assembly Glue	ARALDIT AY103 + HD991 (ratio 10:4)	CERN store
Frame & grid spacer conditioning	Polyurethane (2 component) Nuvovern LW	Walter Mader AG CH-8956 Killwangen
Sandwich structure (external)	Sandwich Stesalit (125 μm)-Honeycomb Nomex (3 mm)-Stesalit (125 μm)	Nomex: Socol, 24 Rue du Lac, F-1020 Renens
Shielding	Aluminium (10 μm)	GDD
GEM foils (50 μm)	50 μm thick kapton, 5 μm copper, 70 μm hole diam., 140 μm pitch	EST
Drift	2 μm Cu on 50 μm kapton	EST
Frame	3 mm thick Stesalit	TA1
Spacers	Vetronite grids 2 mm thick	EST
Gas pipes	PP tube (3 mm diam)	Angst-Pfister
Gas outlet	F-glass + fitting	TA1
PCB	Active area 30.7 x 30.7 cm^2, 2-dim 2x 768 strips, 400 μm pitch	EST
HV boards	Custom made	EST

Table 1. Materials used for the assembly of GEM-detectors.

Part	**Times x Material X_0 x quantity**	**$^{o}/_{oo}$ of X_0**
3 GEMs	Copper: 6 x 5 μm Cu (X_0=14.3 mm) x 0.8 Kapton: 3 x 50 μm kapton (X_0= 286 mm) x 0.8	1.68 0.42 TOTAL: 2.1
1 Drift	Copper: 1 x 5 μm Cu x 1 Kapton: 1 x 50 μm kapton x 1	0.35 0.17 TOTAL: 0.52
3 Grid spacers	3 x 2 mm G10 (X_0= 194 mm) x 0.008	TOTAL: 0.25
1 Readout board	Copper (80 μm strips): 1 x 5 μm Cu x 0.2 Copper (350 μm strips): 1 x 5 μm Cu x 0.75 50 μm kapton x 0.2 120 μm G10 x 1 60 μm NoFlue glue (X_0= 200 mm) x 1	0.07 0.26 0.03 0.62 0.30 TOTAL: 1.28
1 Shielding	1 x 10 μm Aluminum (X_0= 89 mm) x 1	TOTAL: 0.11
2 Honeycomb Nomex	2 x 3 mm Nomex (X_0= 13125 mm) x 1	TOTAL: 0.46
4 Fiberglass Skins	4 x 120 μm G10 x 1	TOTAL: 2.47
		TOTAL: 7.19

Table 2. Material budget for a Triple-Gem detector (active area).

1.3 ASSEMBLY TOOLS

Tools used during assembly are:
GEM transport frame, GEM protection box, precise balance to weight glue components, roller for gluing, plastic container to mix glue, steel stick to mix glue, N_2 gun (with filter), clean room paper, ethanol for cleaning the tools, protection clothing (overall, shoes protection, facial mask, gloves), Scotch tape, weights, protection Mylar foils, Plexiglas protection, HV P.S. and voltmeter, dehumidifier, thermometer, hygrometer.

2. MATERIAL PREPARATION

All these procedures are considered as preparation steps for the final assembly of a triple-GEM detector that will be described chronologically in section 3. The gluing steps are explained in detail in section 4.

2.1 GLUE MIXING

A two component glue is used to assemble the chamber, Araldit AY103 + Hardener HD991, ratio 100:40, by weight.
The glue is usually prepared mixing 30 gr of glue and 12 gr of hardener. They are mixed together in a plastic glass and stirred by hand with a steel stick for a minimum of 4 minutes.
After this action, glue can be used for about 1 hour and the polymerization takes around 16 hours at 30-35^{o}C.

2.2 SANDWICH STRUCTURE + DRIFT

The main support frames of the chamber are two sandwiches of Stesalit (125 μm)-Honeycomb Nomex (3 mm)-Stesalit (125 μm). These parts are assembled outside the clean room, in the TA1 workshop, because a very flat marble table is needed.
One honeycomb, 330x330 mm^2, contains the drift electrode, a 5 μm thin copper layer on 50 μm kapton foil, also with the same dimensions. The other one (Fig. 5) is larger, 500x500 mm^2, contains the PCB with the readout electrodes and hosts also the readout electronics and HV distribution chain. Both parts have a hole in the center matching the central region of the GEM foils, a 50 mm diameter sector that can be deactivated in high intensity runs but activated at low intensity runs for calibration and alignment studies (see Fig. 6). The hole in the honeycomb with the drift is smaller, 35 mm, to avoid deformation of the drift foil during assembly (remember that the assembly is kept in place by vacuum).

The steps to build the top sandwich, the one including the drift electrode, are as follows:

Manufacture the sandwich:
1/ Mix glue,
2/ spread a thin layer of glue on a plastic foil. Make it flat with the help of a roller,
3/ dip the Nomex honeycomb in the thin layer of glue. Apply light pressure on the honeycomb with a roller. Take the honeycomb and repeat the operation with the other side. This method minimizes the quantity of glue,
4/ put the honeycomb on top of the Stesalit foil, which is lying on the flat table. Take the second Stesalit foil and put it on top of the honeycomb,
4/ overlay a rubber protection foil on top of the assembly and weight-load,
4/ the structure is left 1 day at room temperature,
5/ cut out the hole for the beam pipe (35 mm diameter for the drift side and 50 mm for the PCB side) exactly at the center of the honeycomb.

Glue the drift foil:
1/ Lay a clean Mylar foil on the flat table and tension-tape the drift foil on it (copper side facing down),
2/ apply glue with roller on the drift foil and the sandwich (this is done to avoid air bubbles in between) and put them together,
3/ weight-load and let it cure for about 24 hours at room temperature.

2.2.1 Handling the DRIFT foil

Drifts are produced at the EST workshop. Sets are delivered between two rigid plates and clean papers. Use of a plastic box is mandatory. The drift foils are immediately optically inspected. Their quality is usually fine.

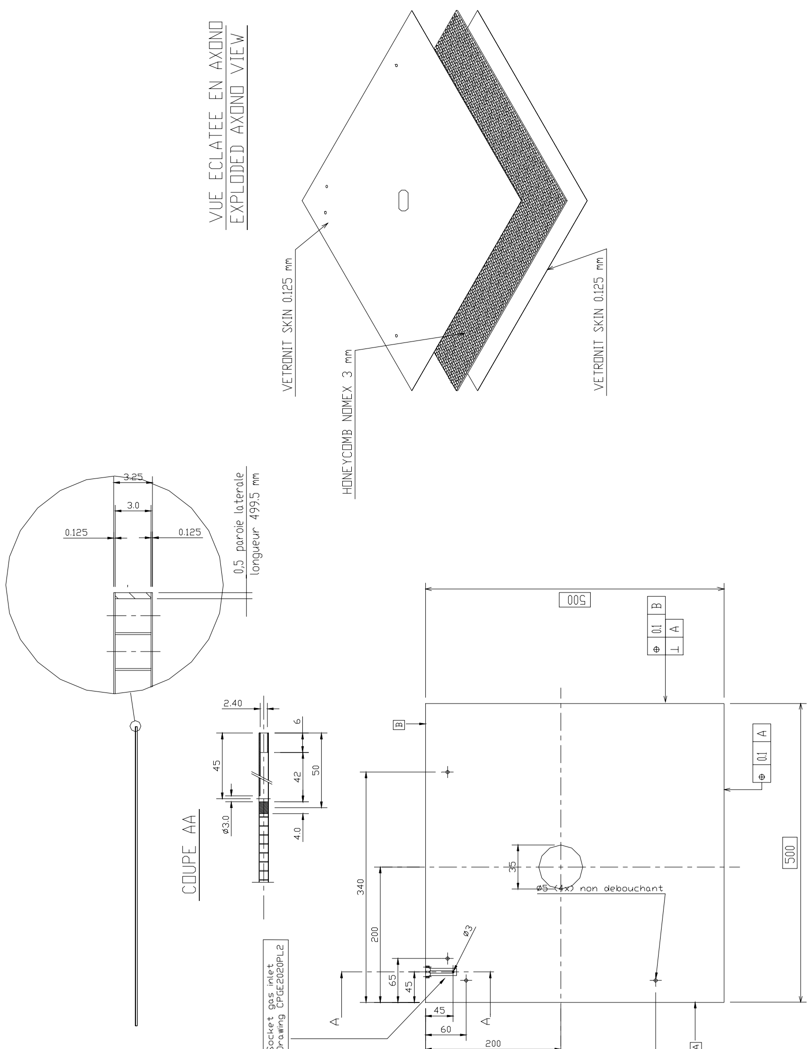

Fig. 5 500x500 mm^2 sandwich of Stesalit (125 μm)-Honeycomb Nomex (3 mm)-Stesalit (125 μm) that acts as main support frame of the chamber. The PCB with the readout strips is glued on top of it.

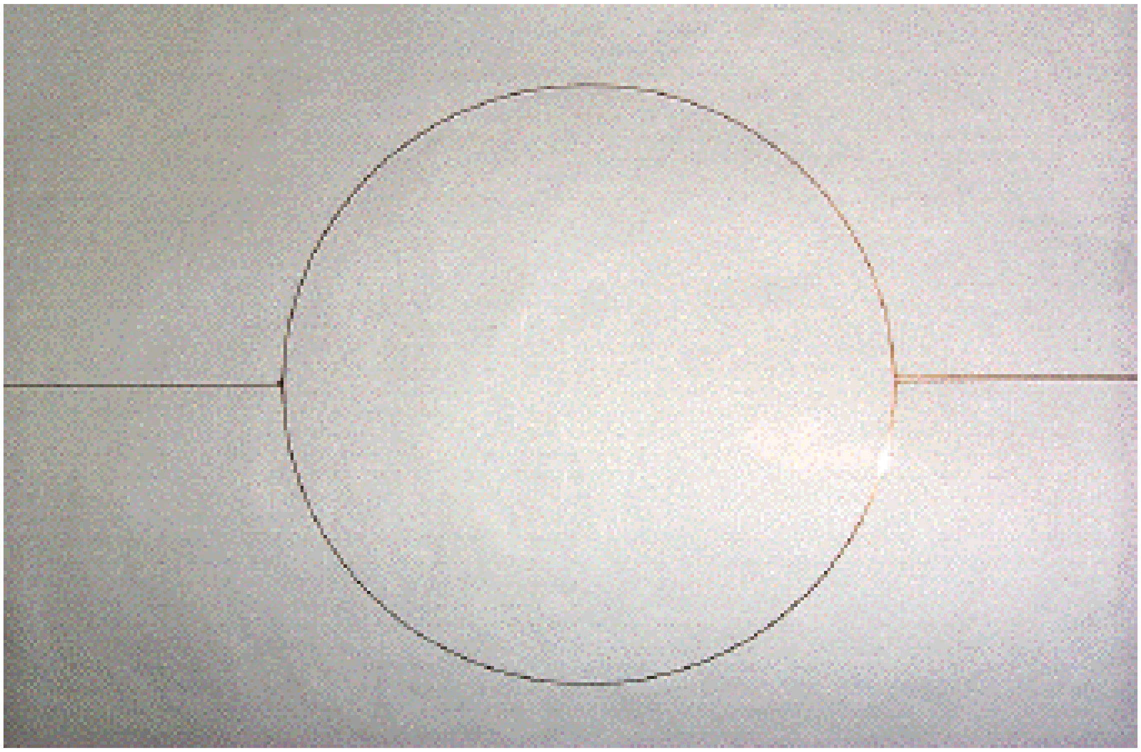

Fig. 6 Close view of the central disk, 5 cm in diameter, etched on one side of each GEM. Independently powered, the disk is used to inhibit detection of the direct beam in the high intensity runs.

2.3 FRAME 3 mm

2.3.1 Frame manufacture

This frame defines the gap between the drift cathode and the first amplification structure.
It is a Stesalit frame, 3 mm high, 7 mm wide, manufactured at TA1 (Fig. 7). The frame contains the gas inlet, where a flexible pipe made out of clean Polypropylene is inserted; some grooves are machined in the frame to facilitate gas distribution in the chamber, according to Fig. 8.
The part of the frame in contact with the active area of the detector is sprayed, to avoid spikes, fibers, etc, with a two-component Polyurethane with a curing time of around 24 hours at room temperature.

2.3.2 Cleaning

The frame is cleaned in an ultrasonic bath with demineralized water for 4 minutes. Proceed as follows:
1/ Introduce the frame in the cleaning-box and fill it up with demineralized water. Place the cleaning-box in the ultrasonic bath,
2/ leave it there for 4 minutes, pulling the grid up and down sometimes,
3/ dry it out in the oven at 40 ^{o}C for 4 hours.

2.3.3 HV test

The frame, once sprayed with Polyurethane and clean, is HV tested to verify its insulation. This is done placing the frame in between two copper foils that are put under 5 kV within the clean gas box.

FRAME VALIDATION | **Frames hold 5 kV in air.**

If sparks occur, the frames will be left in the gas box for some hours (two hours is usually sufficient) and tested again. If sparks are remaining the frames could be inspected with the microscope. Sometimes dust particles are left on the frame. They can be removed. After a repeated cleaning procedure the grids will usually show the expected behavior.

2.3.4 Assembly of the gas input pipe

Glue a PP pipe, coming out 15 cm, in the slit of the frame.

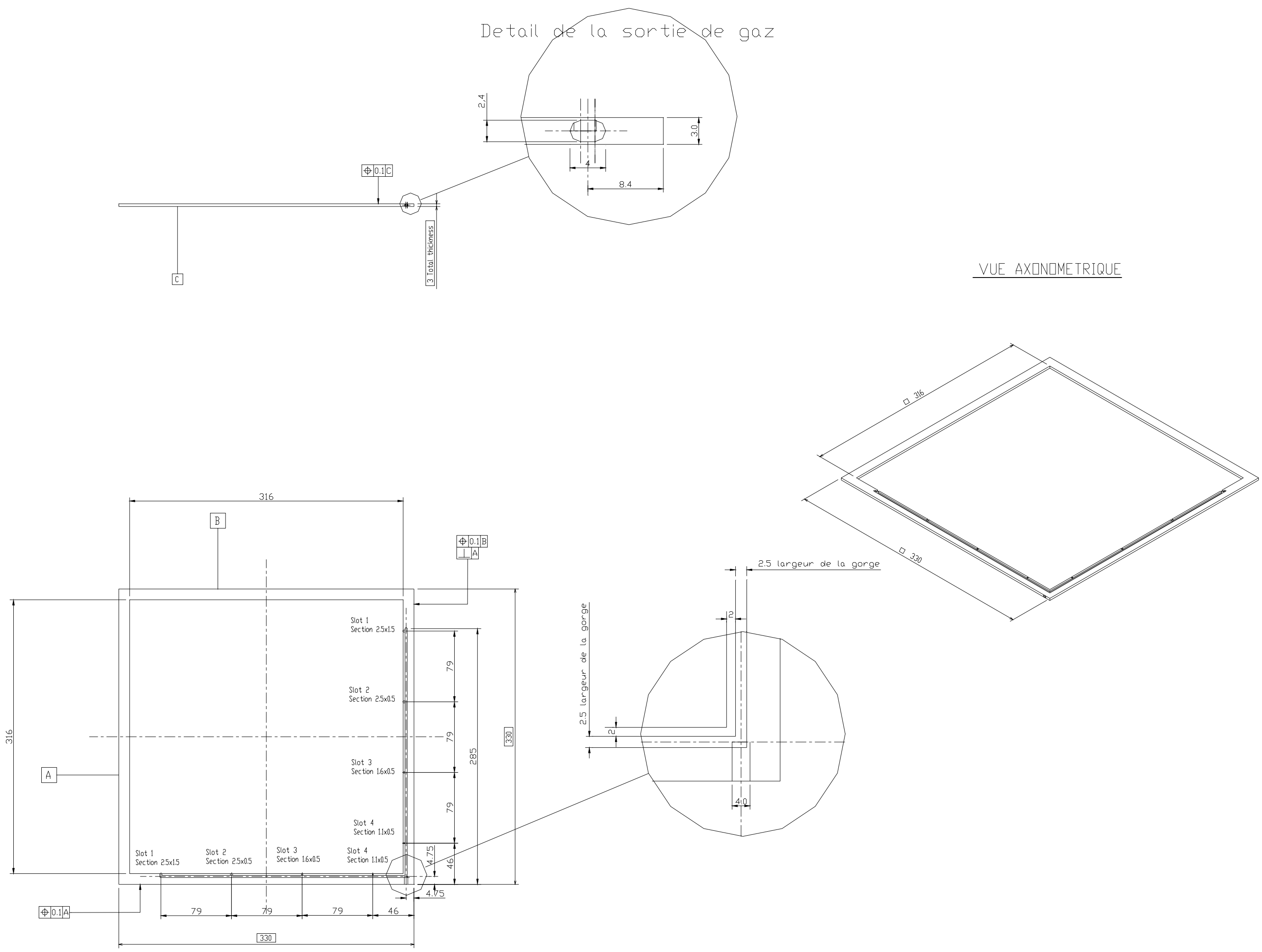

Fig. 7 Stesalit frame, 3 mm high, that contains the input gas pipe; some grooves are machined in the frame to facilitate gas distribution in the chamber.

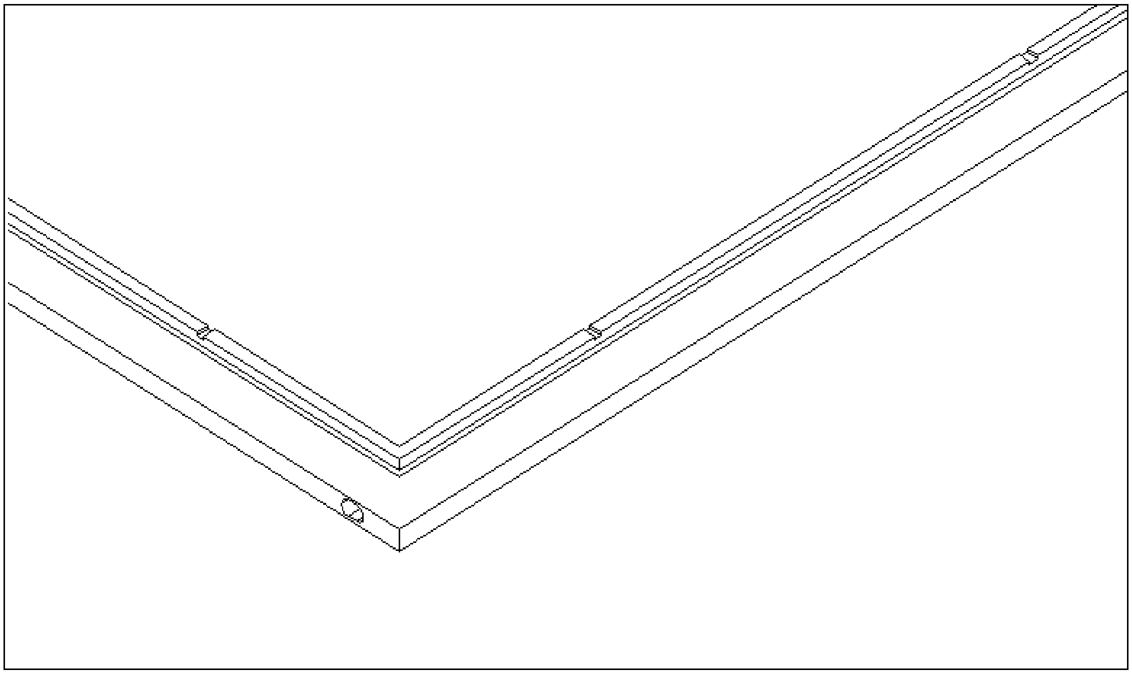

Fig. 8 Detailed drawing of the gas distribution channel machined in the 3 mm frame.

2.4 SPACERS

2.4.1 Spacer manufacture

Spacers are grids 2 mm high manufactured at EST according to Fig. 9. They are completely symmetric. The raw material is doublesided copper Fiberglass. It is used because of the excellent thickness uniformity. The copper is completely removed in chemical baths.

After machining, grids are cleaned with sandpaper to remove dust and residual fibers. The surface in contact with the active area of the detector (i.e., the grid structure and inner part of the frame) is coated with a thin layer of sprayed polyurethane to avoid surface irregularities, residual fibers or sharp edges.

2.4.2 Cleaning

The frame is cleaned in an ultrasonic bath with demineralized water for 4 minutes. Proceed as follows:

1/ Introduce the frame in the cleaning-box and fill it up with demineralized water. Place the cleaning-box in the ultrasonic bath,

2/ leave it there for 4 minutes, pulling the grid up and down sometimes,

3/ dry it out in the oven at 40 ^{o}C for 4 hours.

2.4.3 HV test

They are finally tested under HV as for the 3 mm frame.

GRID VALIDATION **Grids hold 5 kV in air.**

If sparks occur follow the same procedure as for the frames.

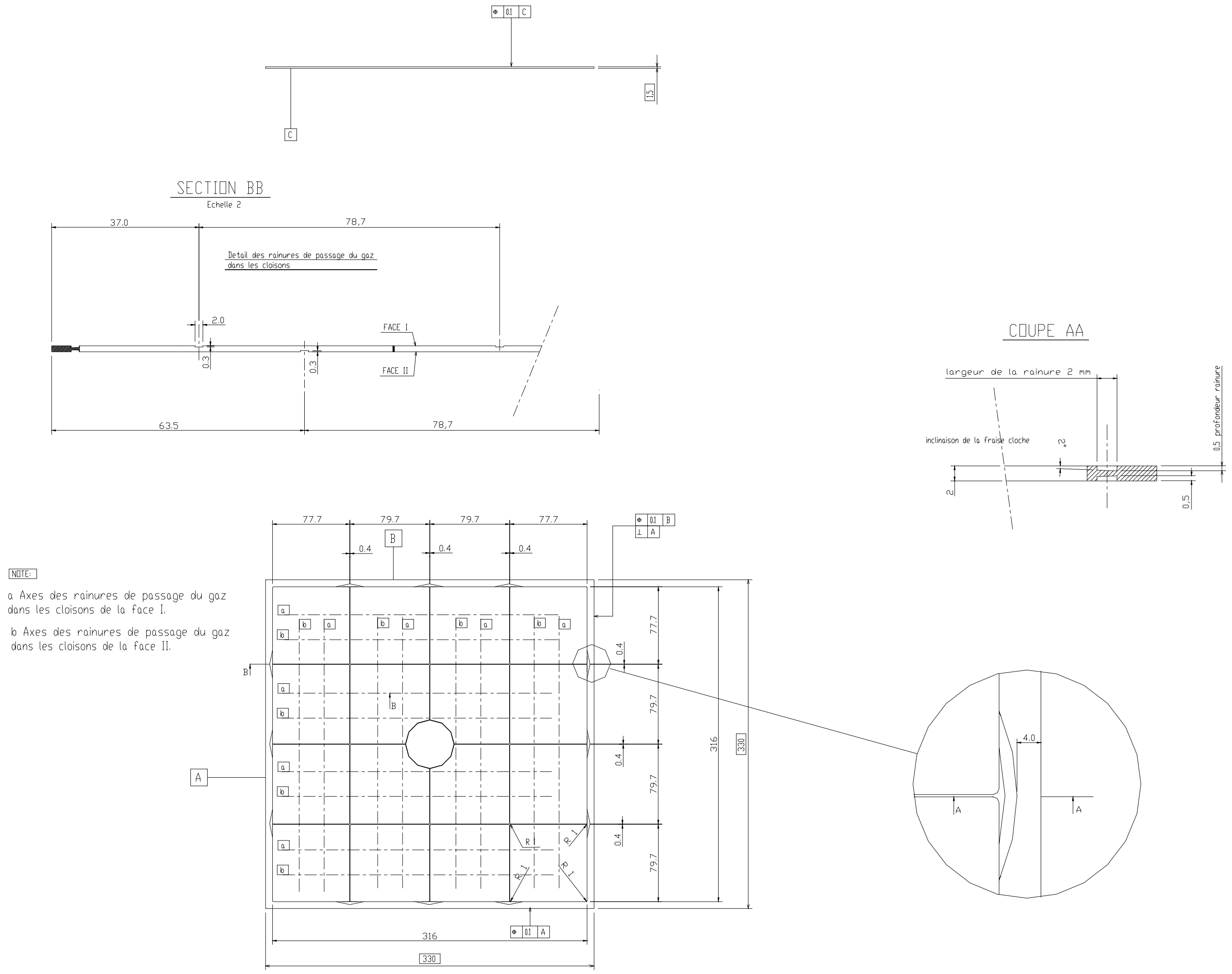

Fig. 9 The grid used as spacer between GEM foils is 2 mm high and the frame width is 7 mm.

2.5 GEMs

2.5.2 Handling GEMs

GEMs are produced at the EST workshop. Fig. 10 shows a picture of a GEM, where the sector structure is visible.

A first quality check is done in place, and GEMs are initially accepted for chamber production if the resistivity in air between the two sides exceeds 2 Gohm per sector. The hole diameter and pitch are also verified in place and they should be 70 +/- 5 and 140 +/- 5 μm respectively.

GEMs are delivered inside a clean Plexiglas box, each foil between two clean papers. They are immediately identified with a unique ID-number. The ID-number looks as ZXX, being Z a character that changes for each new production and XX a number.

GEMs are always kept between two rigid plates and clean papers. They are stored and always handled inside the clean room and <u>facial mask and gloves are always worn.</u>

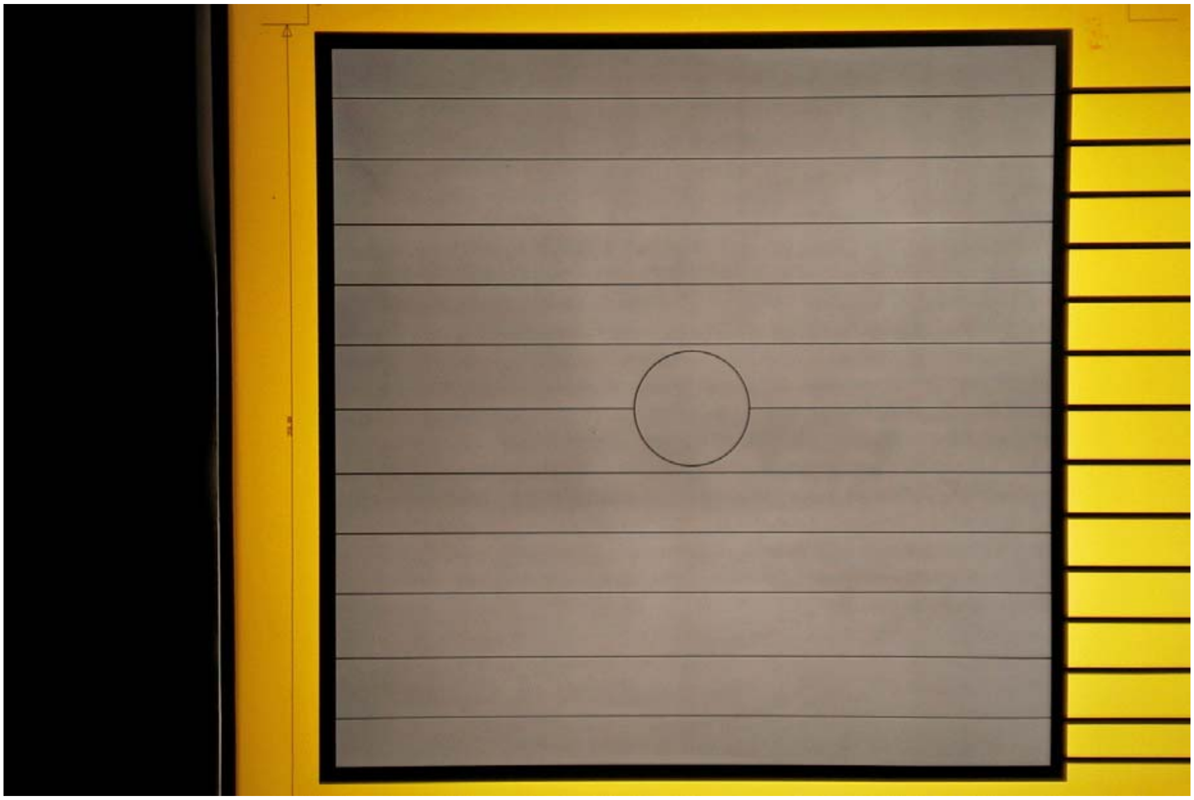

Fig. 10 Picture of a GEM foil.

2.5.3 GEM Selection

GEMs are tested at TA1, verifying optical quality and HV behavior. GEMs passing the criteria explained below are stored in clean conditions (between two rigid plates and clean papers) until the moment they will be use for chamber production.

2.5.3.1 Optical inspection

A first optical inspection is done by eye, followed by a more extensive optical inspection performed under the microscope at the clean room. GEMs are also put on top of a light table and pictures are taken with a digital camera to verify the uniformity of the foils. The presence of a few spots (local absence of the metal and underlying kapton), due to unavoidable inhomogenety in the material, has no consequences in the general operating behavior unless the area or number of spots severely exceed. GEMs are rejected if any of the criteria specified below is not fulfilled.

GEM VALIDATION	**Clean** **The two sides are well aligned** **Maximum misalignment between kapton and copper holes is 10 μm** **Sector separation is correct, i.e. no holes are cut**

A further inspection is done at 'Braem's lab' (3 R-020) which accommodates a microscope with connected digital camera. Hole diameters, focussed on Cu as well as on Kapton at six points at the corners and around the center (see sheet) will be photographed and measured.

2.5.3.2 HV test

1/ Gently flush the GEM with the nitrogen gun to remove dust,
2/ put the GEM inside the Nitrogen box (minimum flow 15 l/h),
3/ do and verify the connections between GEM pads and HV,
4/ close the box and flush it for 2-3 hours with nitrogen,
5/ apply HV individually to each sector; the non-sectored side is put on ground.
Note: for a raw GEM, i.e., not stretched or not glued to a frame, ground also the neighboring sectors. During chamber assembly, the neighboring sectors are left floating.
The maximum current in the power supply is set to 50 nA. The HV is increased in steps of 10 V/s up to a maximum of 600 V for raw GEMs, respectively 550V for treated GEMs. The behavior (leak current and number of sparks, if any) of each sector is record in a Test-sheet.
Note: if a spark occur, wait some minutes until repeating the ramp-up (for example, go the next sector).
6/ store GEM in the original papers.

The GEM is accepted if, for each individual sector:

GEM VALIDATION	**Leak current per sector at 500 V is lower than 5 nA (R>100 GOhm)** **Sector can stand 600 V respectively 550V for more than 2 minutes without sparks.** IMPORTANT: to avoid unnecessary damages, DO NOT EXCEED 600 V!

IMPORTANT: we have observed that weak sectors that are HV trained at this stage to fulfill the above conditions are not permanently recovered and will show problems during chamber operation. Consequently they will not be used for chamber construction. However, in some cases, a raw GEM with a weak sector can be given back to the EST workshop to perform additional cleaning (done by Rui de Oliveira).[2]

2.6 PCB

The PCB, a gold-plated double-sided printed circuit with strips 80 μm and 350 μm wide in each side with 400 μm pitch, is manufactured at EST. The masks are measured and only used for PCB production if the distance between first and last strip at 3 different positions for both coordinates does not vary more than 30 μm with respect to the nominal dimension. At EST they also check if shorts occur between both coordinates. This test is repeated in the clean room at TA1. After these tests the active area is covered with a protective foil until the detector and the PCB are connected.

The test to validate the manufactured PCB consists of measuring the distance between first and last strip at 3 different positions for both coordinates. The distance between first and last strip at 3 different positions

[2] The additional cleaning performed at EST by Rui de Oliveira consists of introducing the GEM foil in several baths, described roughly below and just for information:
1/ cleaning agent NGL 17.40 Alu, 2 minutes
2/ water, 30 seconds
3/ epoxymod-mlx A, 15 seconds and epoxymod-mlx B 15 seconds
4/ water, 10 seconds
5/ finisher PHP, 30 seconds
6/ water, 30 seconds
7/ acide chromique, 10 seconds
8/ water, 5 seconds
9/ deionized water-jet
10/ alcohol-jet
11/ oven 80 degrees for 2 minutes

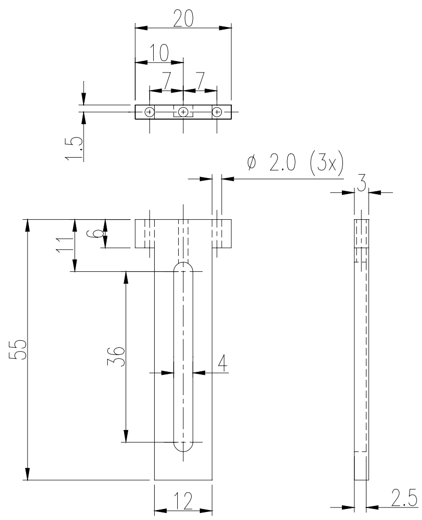

Fig. 11 AutoCad drawing of the gas outlet piece.

for both coordinates must not vary more than 100 μm with respect to each other measured strip dimension in each dimension. The measurement must be performed after gluing on the sandwich structure since the PCB is then more or less flat.

PCB VALIDATION	**The distance between 1st and last strip cannot exceed 100 μm from the nominal (306.8 mm).**

For the assembly point of view, the PCB is a part together with the larger bottom sandwich structure. Four days are needed to have a complete part, time mainly defined by the long curing time of Araldit 103 at room temperature. The following steps are done, outside the clean room:

1/ Prepare the sandwich structure (Stesalit and Nomex honeycomb), as described in section 2.2. Curing time is 1 day. The cutout hole for the beam pipe is 50 mm diameter.
The sandwich contains the gas outlet, a piece shown in Fig. 11 that is inserted in the honeycomb fitting a cutout in the top Stesalit skin,
2/ glue a 10 μm aluminum foil (for shielding purposes) on the backside of the honeycomb folding the sides to allow the future connection between the aluminum and the ground copper strip on the front side of the detector (to be connected with conductive epoxy). At the same time, the PCB is glued on the other side structure (curing time around one day),

3/ machine the structure (dimension 500x500mm): drill 4 holes (5mm) for alignment with GEMs; these holes are drilled at very precise positions with respect to the PCB. Drill trough the PCB a 3 mm diameter hole to connect to the gas outlet piece,
4/ glue sockets in alignment holes (with Araldit Rapid),
5/ clean very well the assembly and specially the gas outlet piece; pull in and glue the PP pipe.

3 ASSEMBLY STEPS

Table 3 shows the different assembly steps. The table also includes working and curing times.
The total number of working days to finalize a chamber is 8, including half-day of spare time.

	DRIFT	FRAME	GEM1	GRID 1	GEM2	GRID2	GEM3	GRID3	PCB	TESTING
Day –2	Sandwich assembly Work: 2 h Curing: 16 h	Machining Work: 4 h PU spray Work: 1 h Curing: 24 h	Stretch Work: 1 h Curing: 16 h	Cleaning Work: 1 h PU spray Work: 1 h Curing: 24 h		Cleaning Work: 1 h PU spray Work: 1 h Curing: 24 h		Cleaning Work: 1 h PU spray Work: 1 h Curing: 24 h		
Day –1	Machine sandwich Glue drift foil Work: 2 h Curing 16 h	HV test Work: 1h Glue PP pipe Work:0.5 h Curing: 16 h	HV test Work: 2 h	HV test Work: 1 h	Stretch Work: 1 h Curing: 16 h	HV test Work: 1 h		HV test Work: 1 h	Glue sandwich Work: 2 h Curing: 24 h	
Day 0		Glue Drift+Frame Work: 1.5 h Curing: 16 h			HV test Work: 2 h		Stretch Work: 1 h Curing: 16 h		Machining Work: 2h Glue Mylar Work: 1 h Curing: 24 h	
Day 1			Glue GEM1 Work: 1.5 h Curing: 16 h				HV test Work: 2 h		Glue PCB Work: 1 h Curing: 24 h	
Day 2			Cut GEM1 Work: 1 h HV test Work: 2 h	Glue GRID1 Work: 1 h Curing: 16 h						
Day 3				HV test Work: 2 h	Glue GEM2 Work: 1.5 h Curing: 16 h					
Day 4					Cut GEM2 Work: 1 h HV test Work: 2 h	Glue GRID2 Work: 1 h Curing: 16 h				
Day 5						HV test Work: 2 h	Glue GEM3 Work: 1.5 h Curing: 16 h			
Day 6	**Preparation work for the next chamber**						Cut GEM3 Work: 1 h HV test Work: 2 h	Glue GRID3 Work: 1 h Curing: 16 h		
Day 7								HV test Work: 2 h	Glue PCB Work: 2 h Curing: 24 h	
Day 8			**Start new chamber**						Glue: tightness Work: 1 h Heat up the chamber Curing: 24 h	
Day 9									Leak test Work: 2 h Glue HVboard Work: 1 h Curing: 1 h	READY

Table 3. Work flow to assemble a triple-GEM detector.

4 GLUING STEPS

4.1 GLUING 3 mm FRAME TO DRIFT

1/ Mix glue outside the clean room,
2/ enter the clean room wearing protective clothing,
3/ place the 3 mm frame on the assembly template, using the internal alignment pins,
4/ take the gluing wheel, place it on the positioning pins and apply glue on the frame, passing several times over the same surface. The wheel is designed to apply glue over 4 mm of frame to avoid glue diffusing inside the active area of the chamber when weight-load is applied. The glue is taken rolling the wheel on a plastic foil where the glue has been previously spread,
5/ remove the frame from the template and place the sandwich+drift (copper side facing up) using the alignment pins, as shown in Fig. 8,
6/ protect the assembly against glue droplets with a new and clean thin Mylar foil which has been previously cut to match the active area of the detector,
7/ apply vacuum,
8/ turn the 3 mm frame upside down and put it on top of the drift, positioned as in Fig. 12 (note the orientation of the PP tube),
9/ cover the assembly with Mylar foil and lay on top the Plexiglas protection,
10/ apply weight all around the frame,
11/ Close mounting template with cover, ensure nitrogen flow and apply 30 ^{o}C. Curing time: min of 16 h,
12/ put the assembly in the oven at 40 ^{o}C for 2 hours to ensure perfect glue polymerization.

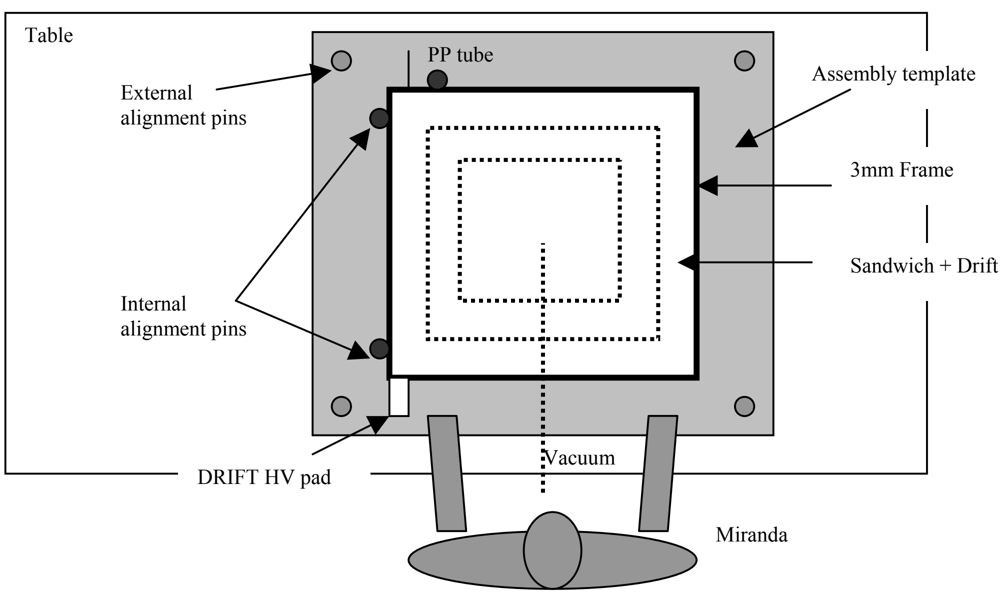

Fig. 12 Step 1 of assembly: positioning of SANDWICH + DRIFT on assembly template

4.2 GEM1

4.2.1. Tension the GEM

The first step to glue a GEM foil in the detector is to tension-tape the foil on a temporary frame, so-called the transfer frame (Fig. 13). This action is carried out, in parallel to other work, at least one day before the GEM will be glued to the chamber. The following steps are done:
1/ Mix glue outside the clean room,
2/ enter the clean room wearing protective clothing,
3/ take a transfer frame, which is larger than the final detector size, and apply scotch tape all around covering around 3 cm from the edge (this will avoid glue where the tape will be positioned),
4/ apply glue on the transfer frame edges with the roller,
5/ put GEM (sectors facing up) on the transfer frame. The position is defined by the coincidence between the holes drilled on the GEM foil and the white round marks at the corners of the transfer frame,
6/ apply light tension to the GEM with the help of Scotch tape glued all around,
7/ protect the GEM with a new, clean thin Mylar foil,
8/ weight-load (the areas with glue) to keep the foil under tension during curing (min: 16 h in air),
9/ test the HV behavior of the GEM, in the Plexiglas box, applying the quality selection criteria specified in section 2.5.2.2.

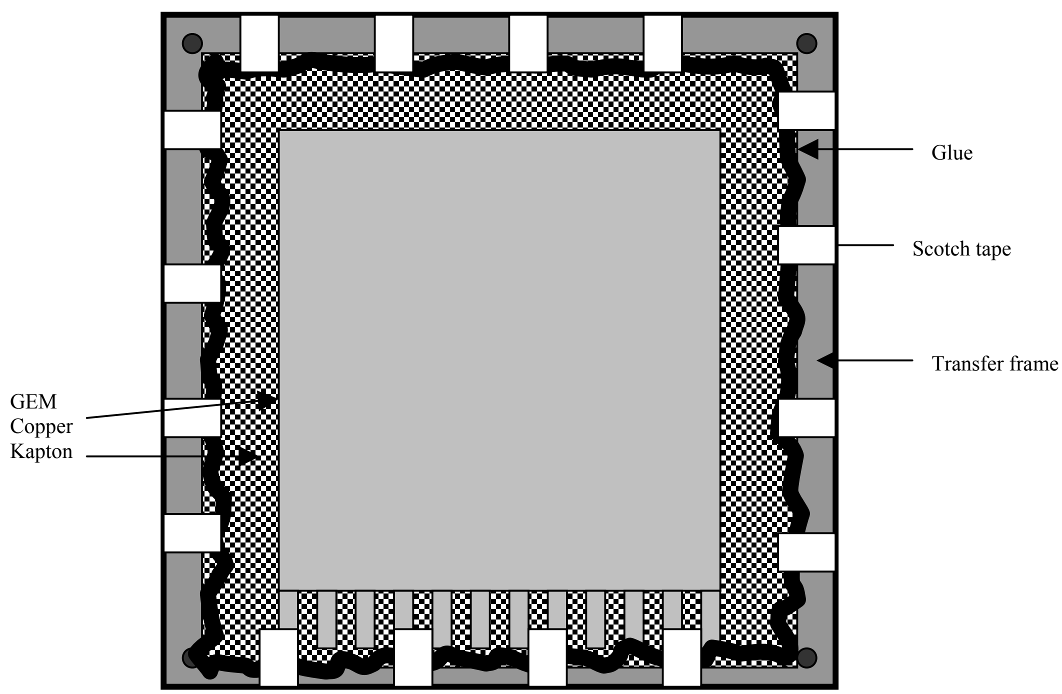

Fig. 13 Each GEM foil is tension-tape on a temporary transfer-frame before is glued to the assembly.

4.2.2. Gluing the GEM1

1/ Mix glue outside the clean room,
2/ enter the clean room wearing protective clothing (mask, gloves),

3/ mount the drift part on the template and fix it with vacuum; orientation as shown in Fig. 14; connect the gas pipe with the N_2-gas line (flow ~ 5 /h).
4/ protect the assembly with a new and clean thin Mylar foil, which has been previously cut to match the active area of the detector,
5/ fix the gluing wheel on the external alignment pins of the template,
6/ remove the inner alignment pins from the template,
7/ apply glue with wheel, leaving around 3 mm free of glue at the inner edge of the 3 mm frame; this avoids glue dripping out and entering in the active area of the detector,
8/ take out the gluing wheel,
9/ gently flush the GEM on the transport frame with nitrogen,
10/ take the GEM on the transport frame, with the non-sectored side facing you (i.e., pad from that side of GEM is at your right) as shown in Fig. 9, and overlay it on the 3 mm frame. Align it with the help of the external pins,
11/ make some pressure with a clean tissue wherever the glue is to avoid bubbles,
12/ apply weights,
13/ put cover on the template, ensure nitrogen flow and wait 16 hours for glue polymerization.

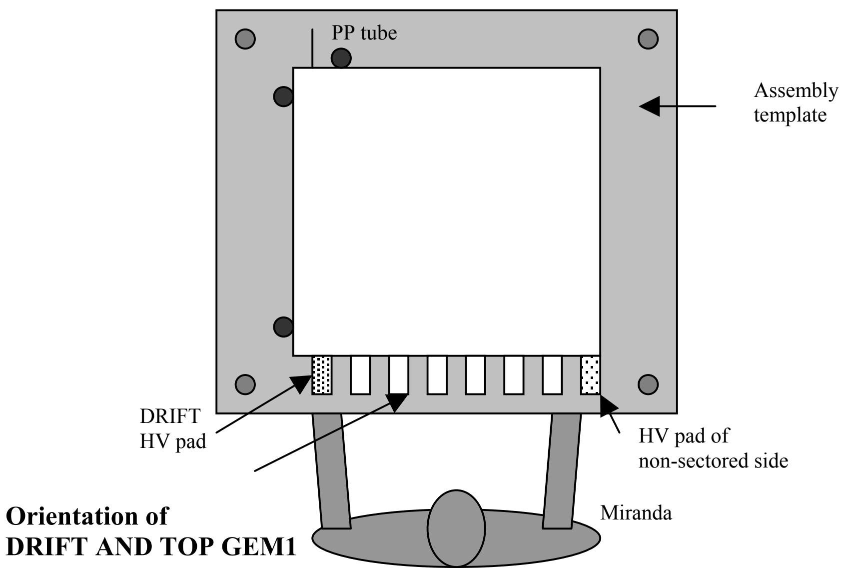

Fig. 14 Orientation of assembly during the gluing of TOP-GEM1.

4.2.3 Cut out GEM1 from the transfer frame
GEM has to be cut from the transfer frame. Proceed as follows:
1/ Wear protective clothing,
2/ cut the vacuum and remove the assembly from the template,
3/ turn it upside-down and lay it on the table,
4/ roughly cut GEM with a scalpel,
5/ precise cut (i.e., cutting very close to the frames) the rests of kapton with a scalpel. Note that the side where the HV pads come out is left as an entire part to facilitate HV quality tests.

4.2.4. Assembly test
After any assembly step, GEMs are HV tested, following the steps described below:

1/ Wear protective clothing (mask, gloves),
2/ take the assembly and put it inside de Nitrogen box, doing and verifying all connections between GEM pads and HV,
3/ close the box and flush with Nitrogen (minimum flow 15 l/h), for about 1.5 hours,
4/ apply HV to each sector. The HV is increased in steps of 10 V/s up to a maximum of 550 V. The behavior (leak current and number of sparks, if any) of each sector is record in a Test-sheet.

The GEM is accepted if fulfills the validation requirements specified in section 2.5.2.2 (GEM VALIDATION: leak current per sector at 550 V is lower than 5 nA and sectors can stand 550 V for more than 2 minutes without sparks).

4.3 GRID1

4.3.1 Gluing the GRID1

1/ Mix glue outside the clean room,
2/ wear protective clothing (mask, gloves),
3/ put the grid on the mounting template,
4/ protect the grid against glue droplets with a new and clean thin Mylar foil which has been previously cut to leave free the 7mm wide frame,
5/ take the gluing wheel and place it on the positioning pins. Apply glue on the grid-frame, passing several times over the same surface. The glue is taken rolling the wheel on a plastic foil where the glue has been previously spread. The grooves in the grid-frame (Fig. 15) prevent from glue flowing through the grid and entering the active area,
6/ remove GRID from template,
7/ put the chamber on the template with the help of the alignment pins and fix it with vacuum; connect the gas pipe with the N_2-gas line (flow ~ 5 /h).
8/ put the grid on top of the assembly with the help of the alignment pins,
9/ put a Mylar foil to protect the GEM+GRID, and lay on top the Plexiglas cover,
10/ weight-load,
11/ cover the box, ensure nitrogen flow and heat up to 30-35 ^{o}C. Curing time: 16 hours.

4.3.2 Assembly test

Proceed as described in section 4.2.4.

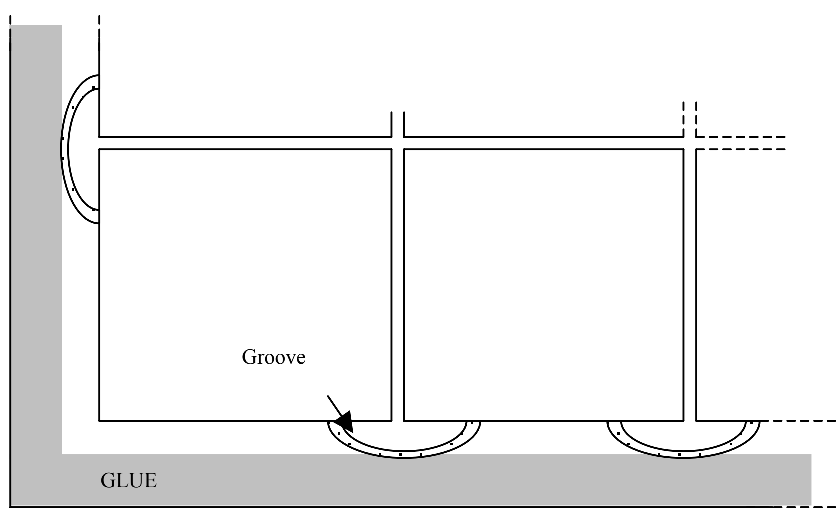

Fig. 15 Part of the 2mm GRID, showing the protection grooves and how glue is applied on it.

4.4 GEM2

Follow steps as described for GEM1 in section 4.2.
The only differences are:
A/ GEM orientation: the HV pads are perpendicular to the pads of GEM1 (see Fig. 16).
B/ Assembly test includes the HV test of GEM2, followed by GEM1

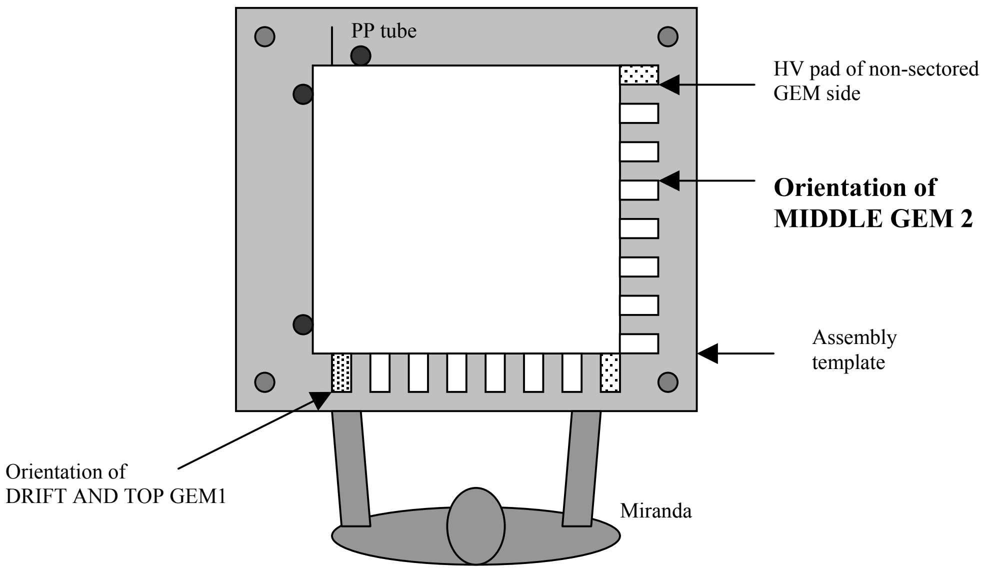

Fig. 16 Orientation of assembly during the gluing of TOP-GEM1.

4.5 GRID2

Follow steps as described for GRID1 in section 4.3.

4.6 GEM3

Follow steps as described for GEM2 in section 4.6, taking into account that GEM3 has the same orientation than GEM2 (see Fig. 16).
Assembly test includes the HV test of GEM3, followed by GEM2 and GEM1.

4.7 GRID3

Follow steps as described for GRID1 in section 4.3.

4.8 PCB

1/ Mix glue outside the clean room,
2/ wear protective clothing (mask, gloves),

3/ flush the PCB with the nitrogen gun to remove dust and lay it on the gluing table,
4/ insert the 4 alignment pins in the PCB sandwich,
5/ mount the gluing wheel on the template,
6/ position the assembly (glued GEMs and grids) on the mounting template,
7/ protect the grid3 against glue droplets with a new and clean thin Mylar foil which has been previously cut to leave free the 7mm wide frame,
8/ apply glue on the grid-frame, as usual,
9/ throw away the protection foil,
10/ remove the assembly from the template, turn it upside-down,
11/ lay it on top of the PCB with the help of the alignment pins, oriented as shown in Fig. 17,
12/ take a soft, rubber foil to protect the structure,
13/ weight-load; curing time: > 16 hours in air.

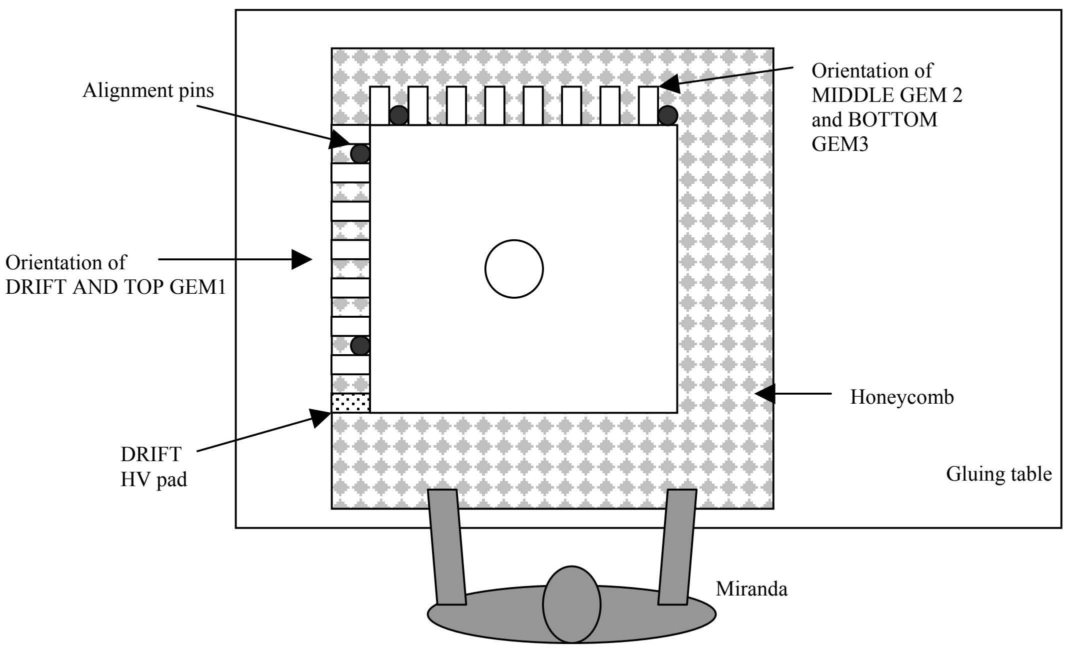

Fig. 17 Final step to assemble the chamber carried out in a flat table. The assembled GEMs are glued on top of the honeycomb with the help of precise alignment pins inserted in the honeycomb.

5 FINAL STEPS AND QUALITY CONTROL

At this stage the chamber is closed and taken out from the clean room. At the TA1 workshop some final work is done. Then the chamber is moved to the laboratories at building 28, where it is sealed, tested and finalized.
Sealing the edges is done with Dow Corning (insulating agent), with the help of a dispenser. The surface of the edges is spread homogeneously with Dow Corning and left for several hours until the agent becomes polymerized. The time of polymerization is about six hours. To be on the safe side, the edges containing the bonding pads must be left for at least 12 hours (back-diffusion). After this step the detector will be undergone final quality tests. Fig. 18 summarizes the different tests carried out to qualify a chamber.

To ensure a perfect polymerization of the glue and avoid pollution due to outgassing agents, the completed chamber is put inside an oven at 40^{o}C connected (through the gas chamber inlet) to an open nitrogen flow of 1-2 l/h for at least 12 hours.

SET-UP 1
Completed chamber. Access to individual sectors. NO HV boards

1. GAS LEAK TEST	CO_2
***2.* HV test (500V) of individual sectors**	Ar/CO_2 HV test of individual sectors, grounding everywhere around the sector

ASSEMBLY ROOM

3. Glue HV boards & Make HV connections

SET-UP 2

4. Check for external discharges	CO_2 flushing Ground PCB (Foam+Alu) Apply HV (4.5 kV)
5. Look for signals	Ar/CO_2 Look for signals in bottom GEM (ORTEC preamp.) Apply nominal operating conditions Characterize 13 sectors with: - maximum PH - separation of Ar escape peak.

BONDING WORKSHOP

5. Bonding

SET-UP 3: final DAQ system

6. Fine testing	Ar-CO_2 Gain uniformity, etc…

Fig. 18 Summary of the different tests carried out to qualify a chamber.

5.1 GAS TIGHTNESS CONTROL

Gas tightness is controlled installing the chamber in a clean gas system at building 28 (GDD upstairs laboratory) with pure CO_2:
1/ Fix swagelock connectors (for 3 mm pipe diameter) at the end of each PP gas tube,
2/ fix the chamber in a transport frame with the help of brass fittings, taking care that gas pipes are closed and fixed with tape to the frame,
3/ transport the chamber and connect it to the gas system. The gas flow should be between 60 and 100 cc/min of pure CO_2,
4/ wait at least ½ hour,
5/ take the portable leak hunter and check carefully.

If a leak is detected, apply Dow Corning at that particular spot. Wait for glue polymerization at least 6 h and check leak rate again.

5.2 HV TEST OF INDIVIDUAL SECTORS

At this stage the individual sectors of all GEMs are easily accessible. Each individual sector is put under HV, up to a maximum of 500V, in Ar/CO_2. Their behavior (leak current and number of sparks, if any) is recorded in the unique Test-sheet.

5.3 ELECTRICAL CONNECTIONS

The electrical connections are done in a separated room.
The HV boards, shown not assembled with resistors in Fig. 19, are manufactured on 200 µm fiberglass and coated in the manufacturing process with a 50 µm coverlayer of epoxy to ensure insulation.
They are pre-assembled with resistors, professionally clean and coated with an insulating spray at the CERN/SMD workshop.
The boards are tested up to 5 kV and the value of each individual resistor is verified and record to allow the correct calculation of current flowing through the resistor network.

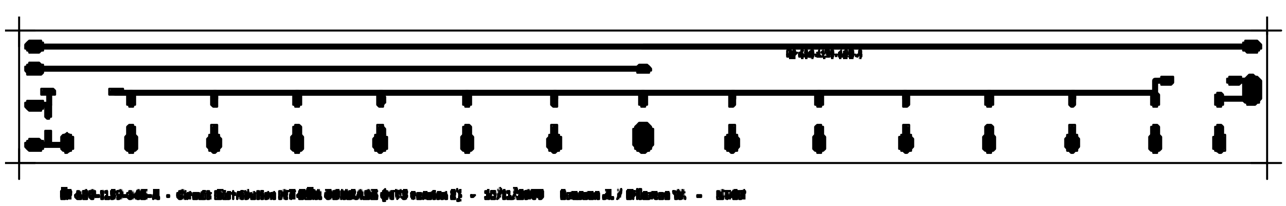

Fig. 19 Picture of the HV boards still not assembled with resistors.

The HV boards are glued with Araldit rapid to the chamber, oriented as shown in Fig. 20, and following the steps below.

1/ Mix Araldit rapid (attention: curing time is 5 minutes),
2/ apply glue on the back of the boards,
3/ lay the homemade Plexiglas protection mask on top of the boards and apply weight.

The GEM HV pads are soldered to the HV boards. 200 V are put across GEMs to verify the right voltage drop in all electrodes. Red paint is applied at each individual spot where any soldering has been made as prevention against corona discharges.
Silver paint is momentarily applied at the PCB to short and ground the readout electrodes as shown also in Fig. 20 to be able to read out the signal. The conductive paint will be simply removed with acetone before the final readout electronics will be bonded.

To verify the electrical connections and discard the presence of external discharges, follow the steps below:
1/ put the chamber under pure CO_2,
2/ apply HV (4.5 kV)
In order to localize discharges, if any, flush individual HV spots with an argon gun.

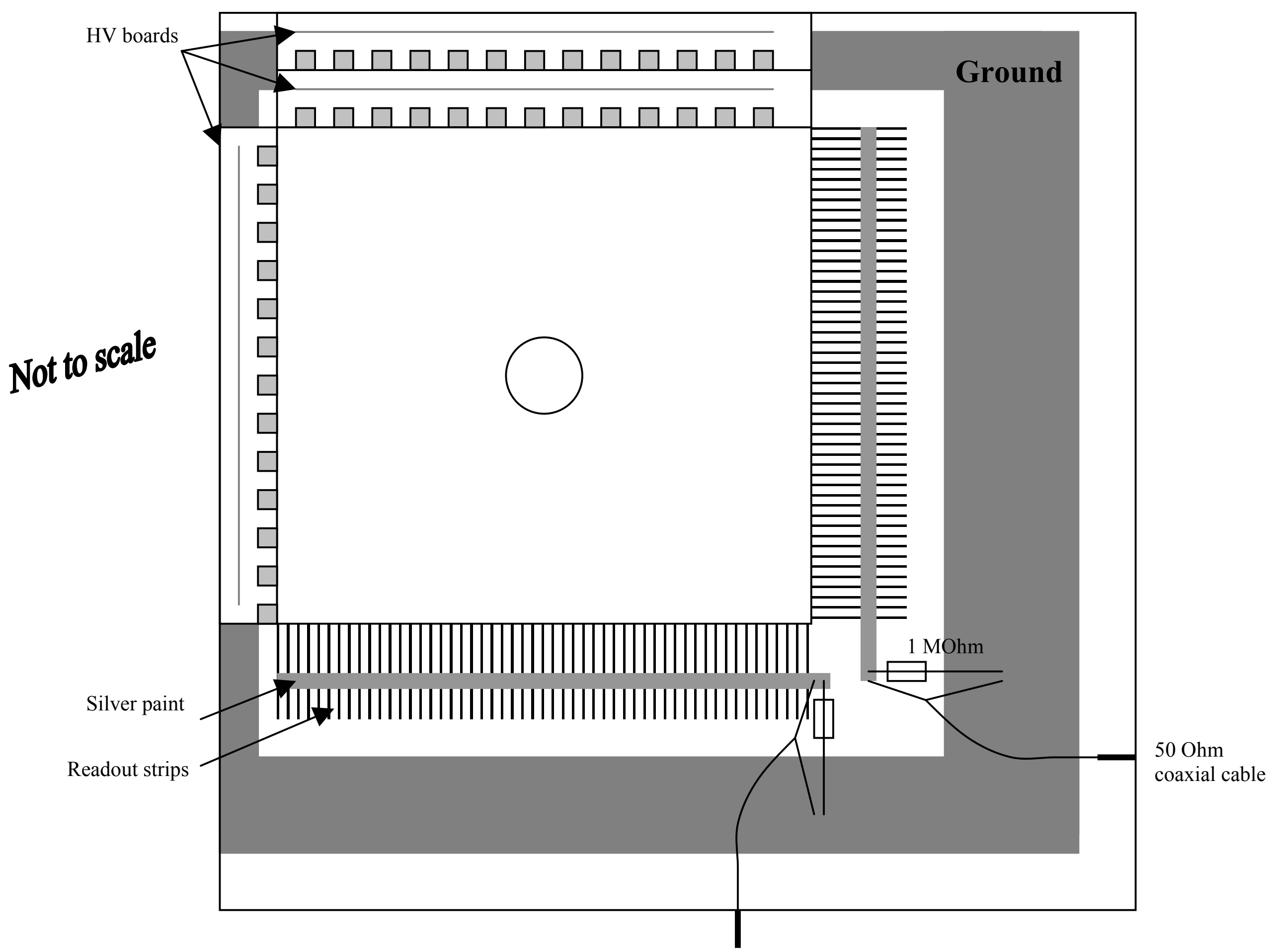

Fig.20 Temporary grounding of the readout strips to allow safe HV operation and easy signal readout prior to the bonding of the final electronics.

LIST OF FIGURES AND TABLES

ACKNOWLEDGEMENTS

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