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Design and Construction of the Wire Chambers for the LHCb Muon System

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Abstract

The LHCb muon system will use Multi-Wire Proportional Chambers (MWPC) in all regions with a particle flux between 1 kHz/cm^2 and 100 kHz/cm^2. After an overview of the chamber requirements and specifications, the design and construction procedures including the quality control of the detector system are described. The electrical layout is discussed and finally the cost breakdown and the construction schedule is presented.

1 Chamber Layout and Requirements

The LHCb muon system will use Multi-Wire Proportional Chambers (MWPC) for the four regions of stations M2 and M3, for regions R3 and R4 of station M1 and for regions R1 and R2 of stations 4M and M5. As the detector layout is fully projective, the chambers and readout pads vary in size for the different regions (see [1] for more details). An overview of the chamber instrumentation is given in Table 1. The full system covered by MWPCs consists of 864 chambers and about 80k FE-channels.

Table 1 Summary table of the MWPC detector

	Station 1	Station 2	Station 3	Station 4	Station 5	Sum
Chambers in Region 1						
Number of Chambers		12	12	12	12	48
Sensitive area (cm^2)		30×25	32.4×27	34.8×29	37.1×30.9	
Anode channels		96	96			2304
Av. wire pad size (mm^2)		6.3×250	6.7×270			
Number of wires		800	864	928	992	4.4×10^4
Cathode channels		128	128	192	192	7680
Cathode pad size (mm^2)		37.5×31.3	40.5×33.7	29×36	31×39	
Chambers in Region 2						
Number of Chambers		24	24	24	24	96
sensitive area (cm^2)		60×25	64.8×27	69.5×29	74.3×30.9	
Anode channels		96	96			4608
Av.wire pad size (mm^2)		12.5×250	13.5×270			
Number of wires		1600	1728	1856	1984	1.7×10^5
Cathode channels		128	64	96	96	9216
Cathode pad size (mm^2)		75.0×31.3	162×33.7	58×72	62×77	
Chambers in Region 3						
Number of Chambers	48	48	48			144
Sensitive area (cm^2)	96×20	120×25	129.6×27			
Number of wires	2560	3200	3456			4.4×10^5
Cathode channels	192	192	192			27648
Cathode pad size (mm^2)	20×100	25×125	27×135			
Chambers in Region 4						
Number of Chambers	192	192	192			576
sensitive area (cm^2)	96×20	120×25	129.6×27			
Anode channels	48	48	48			27648
Wire pad size (mm^2)	40×200	50×250	54×270			
Number of wires	2560	3200	3456			1.8×10^6

Depending on the region, the chambers are readout differently: in region R4 of stations M1 – M3 the chambers have anode wire readout (through decoupling capacitors); in region R3 of stations M1 – M3 and regions R1 and R2 of stations M4 and M5 cathode pads are readout; in regions 1 and 2 of stations M2 and M3 a combined readout of wire and cathode pads is used as a consequence of the required granularity.

The general design and the construction is the same for all chambers. They have 4 separate gas gaps, each with an anode wire plane and – in regions R1 to R3 – a plane of cathode pads. The values for the basic chamber parameters are given in Table 2.

Table 2 Main MWPC parameters

Parameter	Design value
Cathode-Cathode distance	5 mm
Anode-Cathode distance	2.5 mm
Wire spacing	1.5 mm
Wire Diameter	30 μm
Wire potential	3150 V
Wire surface field	260 kV/cm
Cathode surface field	8 kV/cm
Gas mixture	$\mathrm{Ar/CO_2/CF_4}$ (40% 50% 10%)
Primary ionization	≈ 100 e-/cm
Gas Gain	$\approx 10^5$
charge/5 mm track	$\approx 0.8\,pC$
electron drift-velocity	$\approx 90\,\mu$m/ns
ion collection time	$\approx 20\,\mu$s

The main tolerances for the chamber construction are summarised in Table 3. They have been determined with GARFIELD, assuming that a the maximal tolerable variation in gas gain is ±20%. For these simulations only individual parameters have been varied while the other parameters have the design value (see [2] for more details).

Table 3 Main geometrical tolerances for the MWPCs. The first column gives the maximal acceptable deviations for single parameters, obtained from GARFIELD simulations; the second gives the second the required geometrical tolerance of the chambers.

Parameter	Max.Deviation	Tolerance
Panel Thickness		$\pm$ 200 μm
Panel flatness	$\pm$ 75 μm	$\pm$ 50 μm
Gas gap	$\pm$ 80 μm	$\pm$ 70 μm
Wire plane vertical offset	$\pm$ 300 μm	$\pm$ 100 μm
Single wire vertical offset	$\pm$ 250 μm	$\pm$ 100 μm
Wire pitch	$\pm$ 80 μm	$\pm$ 40 μm

2 Chamber Components

The main components for the MWPCs of the muon system are the following:

- Structural panels made of honeycomb, chempir core or polyurethane foam with FR4 cathode laminates (total thickness 10.2 ± 0.2 mm);

- Wire fixation bars (WFB), with traces on it, where anode wires are soldered and glued (2.40±0.08 mm thickness);
- Gold-plated tungsten wires of 30 μm and 100 μm diameter for the sense wires and guard wires respectively;
- FR4 or aluminum frames of 5.0 ± 0.08 mm on the short side of the chamber (SB), where the gas inlets are located;
- Bars of 2.40±0.08 mm thickness on top of the WFBs to close the gas gap over the long side of the chamber (CB);
- Spacers over the long (and possibly also the short) side of the chamber to ensure precision of the gas gap of 5.00 ± 0.08 mm.

2.1 Panels

The panels are the basis of the chamber mechanical structure. The requirement on the flatness of ± 50 μm is of critical importance for gas gain uniformity and consequently for the width of the operational plateau.

A panel consists of two copper clad FR4 (fire-resistant fiberglass epoxy) laminates interleaved with a core. For the core various materials are under investigation. Besides the panels based on honeycomb and polyurethane foam, which are discussed in more detail in the following, other materials like Chempir core have been studied as well [4]. The choice for the core material is still to be made. The honeycomb solution has already been tested with good results. Therefore, FR4-laminates of 1.6 mm thickness with $\approx 30\mu\mathrm{m}$ copper interleaved with 7 mm honeycomb are the baseline panel for the chamber construction (see Figure 1). However, the panels based on polyurethane foam are cheaper and faster to build.

2.1.1 Honeycomb Panels

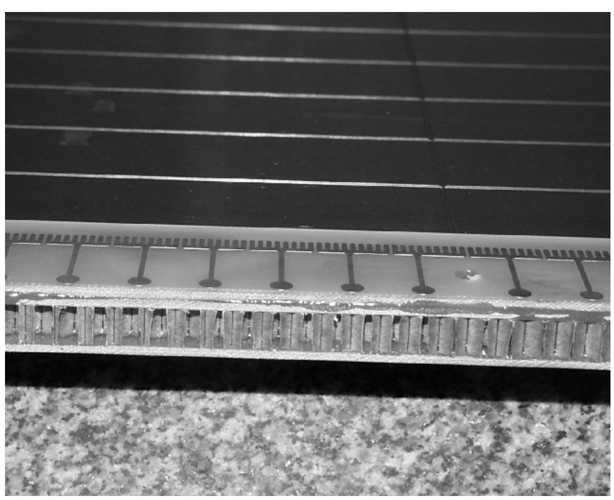

Figure 1 A picture of the PCB-honeycomb-PCB sandwich is shown.

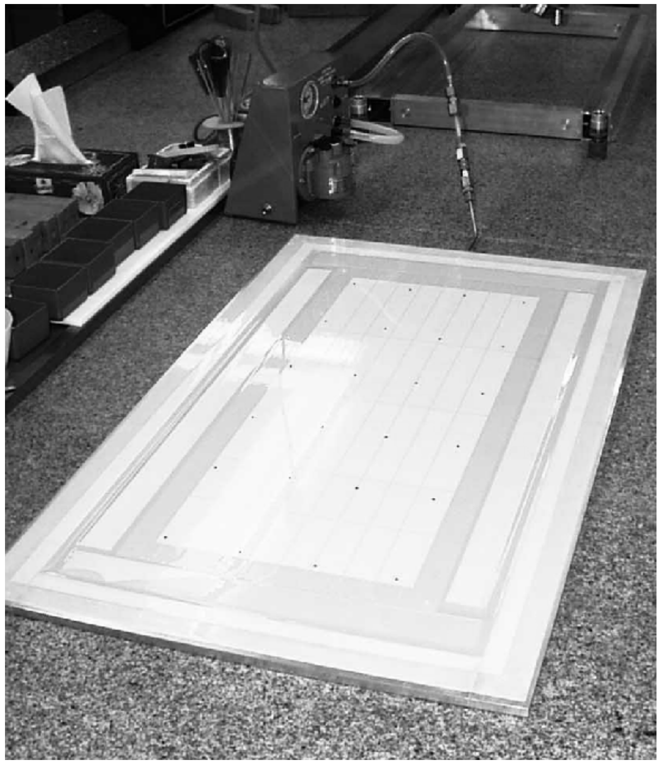

Figure 2 A panel being glued under vacuum pressure.

The flatness of the FR4 laminates (or where applicable, printed circuit boards) and the honeycomb sheets has to be controlled before gluing the panel. Only the components with a flatness within $\pm 50\mu$m are accepted. The chosen PCBs are glued to the honeycomb sheets with Araldite 2011. They should then be left for about 12 hours held to a flat surface by vacuum, as can be seen in Figure 2. The flatness of the final panels must then be measured again. In the panel border regions where screws close the chamber, the pressure put on the honeycomb sandwiches is rather large. Because of that and also to make the soldering of the front-end connectors easier, the honeycomb sheets should be cut smaller than the PCBs. After gluing and soldering the connectors, the space left between the PCBs is filled with Adekit 170 epoxy glue (see Figure 3). In the four corners of the panels an additional plastic spacer could be added to ensure an even better stiffness.

It has been demonstrated in several prototypes that honeycomb panels with the required specification can be produced. However, such panels are rather expensive and their production is time consuming. Therefore other solutions, as discussed in the following, are under investigation.

2.1.2 Polyurethane Foam Panels

The panels are composed of two sheets of FR4 filled with a rigid polyurethane foam[1]. The polyurethane foam is the result of a chemical reaction between two components: the polyol and the isocyanate. The liquid polyurethane components are injected in a mould between the two FR4 sheets, with a low pressure machine (gravity injection). The construction procedure is the

[1] ESADUR120, Tagos srl, Varese (Italy), www.tagos.it

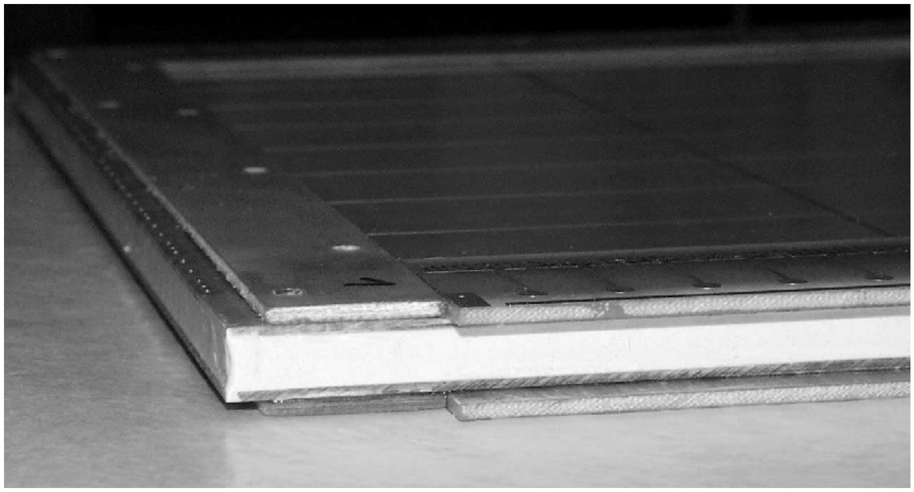

Figure 3 A PCB-honeycomb-PCB sandwich with reinforced borders is shown.

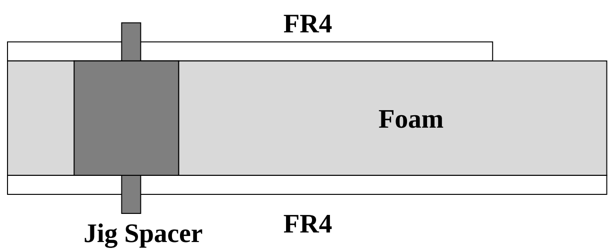

Figure 4 The jig spacer inserted into the polyurethane panel.

following:

1. The mould is opened and the first FR4 sheet is inserted in the mould's cavity;
2. Jig spacers (see Figure 4 and 5) are inserted inside holes in the FR4 sheet;
3. The second FR4 sheet is inserted in the mould: the correct positioning is given by the jig spacers;
4. The mould is closed and the foam is injected through the casting hole.

The advantages of using jig spacers are the correct positioning of FR4 sheets inside the mould and the provision of reference points for the assembly of the various elements of the chamber.

To make the foam injection easier, the temperature is set to 35-38 ^{o}C. The steel mould is built up of two planes that form a 15^{o} angle with the horizontal plane and it sustains the pressure due to the expansion of the foam (5 kg/cm^2). The planarity of the panel is ensured by the precision of the mould surface (0.01 mm). The polymerization time of the foam is 12-18 minutes and the density is 400-600 kg/m^3. The possibility of using a lower density foam is under test. A panel $20\times20\times1$ cm^3 with a rigid polyurethane foam (ESADUR120) has been produced using a non precise mould, showing a very high mechanical rigidity. A precision mould is under preparation (30×30 cm^2) to test the requested planarity and to verify the construction sequence. Tests with less precise FR4 laminates of 0.8 mm are planned as well. A modular die to provide different panels for various chamber dimensions is under study.

Figure 5 Detail of jig and gap spacers inserted in the polyurethane panel.

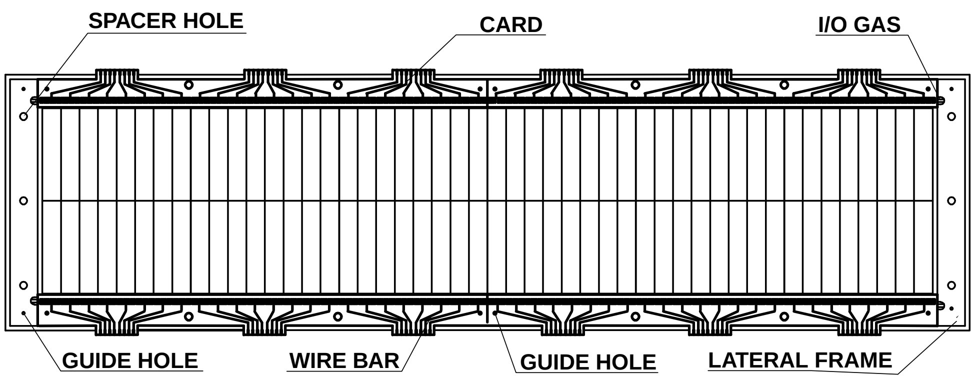

Figure 6 The cathode layout in region 3

2.2 Cathode Planes

Detailed SPICE simulations have been carried out in order to minimise the capacitance and the cross-talk induced by the readout traces running under the cathode pads (see [3] for details). This studies showed that, in order to minimise the cathode capacitance, it is preferable to have two panels with cathodes pads on both sides, instead of having four panels with cathode pads on only one side. Moreover, such a configuration provides better shielding to the cathodes, as they are always surrounded by detector ground.

In all regions the cross talk can be kept below the 5% level, which is well within the requirements for the muon system.

In region R3 the cathode pads can be accessed from the top and the bottom of the chambers (see Figure 6). This avoids the use of cathode-PCB in this region, which is difficult to realize with the required dimensions. First investigations of using a milling machine to realize the cathode structure are promising, but a full test has still to be carried out. Guard traces of 0.5 mm width between the cathode pads are foreseen to minimize the cross talk. The width of the insulating surface between the pads and the guard trace should not exceed 0.4 mm to avoid the problem of charge up at high rates.

In regions R1 and R2 the cathodes have a chess-board structure, as indicated in Figure 7. Only a fraction of the cathode pad signals of region R1 and R2 can be accessed from the border of the chamber. Most of the pads have to be read by traces running on the bottom of the cathode board to the edge of the chamber. A double sided PCB will be used to implement this structure. There special care has to be taken to minimize the capacitance between the readout traces and the pads. The readout traces of 0.25 mm width are separated by 0.25 mm grounded traces with a gap of 0.25 mm. The pads are connected through metallized holes to the readout traces.

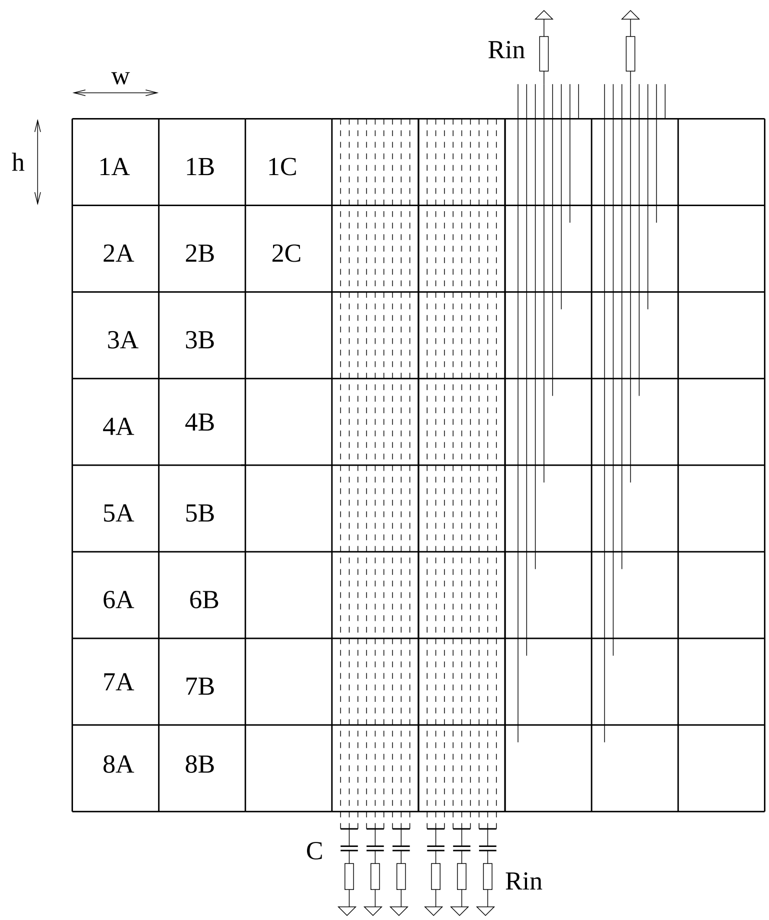

Figure 7 Cathode- and wire-pad structure and readout.

2.3 Wire fixation bars and gap bars

On the long sides of the panels, wire fixation bars are glued. The bars have a thickness of 2.4 mm, so slightly less than the anode-cathode distance. They will be made according to standard printed circuit board technology. A pattern of finger-tip pads is etched on the bars which will be used for soldering the wires. They are interconnected in groups, as indicated in Figure 8.

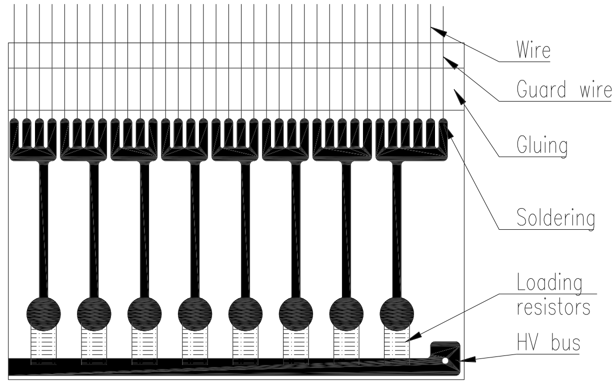

Figure 8 Blow up of a corner of the wire fixation bar.

The grouping of wires is determined in the case of anode wire readout by the required granularity in the x-coordinate. In order to minimize the cross talk in the case of cathode pad readout, wires are grouped together according to the x-dimension of the pads.

The wire fixation bars and the other frames will be correctly positioned on the panels by a set of calibrated cylindrical spacer (5 mm thick) inserted in them. This guarantees the exact gap all along the perimeter of the chamber. In this case the WFBs and the other frames can have standard tolerances and need only the drilling of holes for the cylindrical spacers, and, in case of the side bars, for the gas inlets/outlets. This solution, in addition to be less expensive, has also the advantage to allow for a non critical gluing of all chamber elements.

2.4 Wire

The total number of wires in the chambers under consideration sums up to about 2.5 $\times 10^6$, with a total wire length of about 1200 km. Therefore, much effort has been expended to develop an efficient and reliable scheme of winding and attaching wires, as discussed in section 3.

Gold-plated tungsten wire of 30 μm diameter has been chosen for the wires of the chambers. Measurements show a linear dependence of the elongation on the weight applied up to 140g, as can be seen in Figure 9. At the baseline wire spacing of 1.5 mm and with nominal HV of 3.15 kV, the wires become electro-statically unstable if there tension is below 30 g. The chosen baseline wire tension and its spread is (60 $\pm$ 10) g. This should avoid the before mentioned problems.

A guard wire of 100 μm diameter will be used as last wire to avoid very high fields on the wires at the chamber border. Tests have shown that a single guard wire is sufficient.

3 Chamber Construction

There are two possible ways to build the chambers with the above parameters. One is producing anode panels wired on both sides, the other making panels with wires on one side only. The two options can be seen in the drawing of Figure 10. Both methods have their merits. The main advantages of mono gaps is the fact that the panels can be handled more easily during the detector construction. Moreover, in case of incurable problems during the glueing or soldering process, one would loose only one gap. Double gap wiring, on the other hand, is better adapted to the cathode design, which is based on two double gaps instead of four single gaps, as pointed

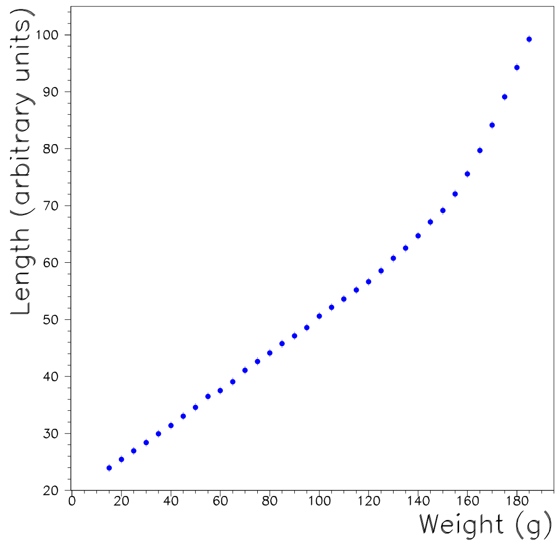

Figure 9 Wire elongation as a function of the weight

out in section 2.2. In addition, all prototypes have been build so far with a double gap structure. Therefore, this design is backed up by experience and positive results from tests. The final choice of the construction method has still to be made.

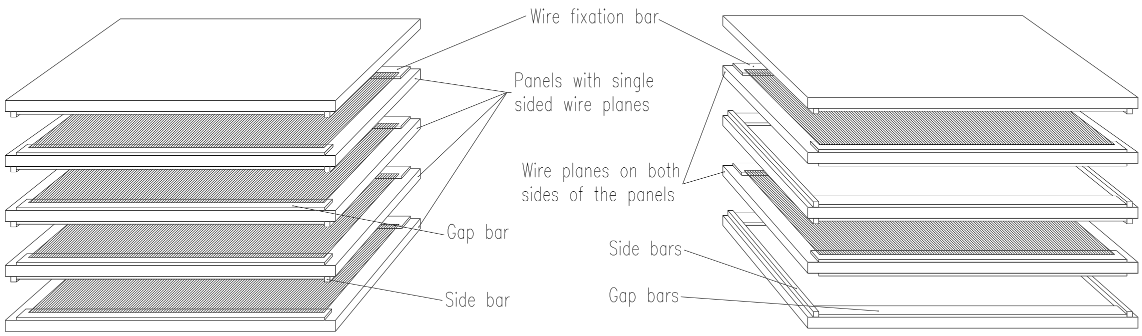

Figure 10 The chamber ready to be assembled with single sided (left) or double sided wired panels.

Prior to the wiring a panel is assembled in the following way:

- the Side bars (SB) are inserted in the jigs and glued to the panels;
- the WFBs are located using the jigs (these are in particular needed if the WFBs are made of several pieces due to the chamber length) and glued to the panels;
- the Closing Bars of 2.4±0.5 mm thickness (CB) on top of the WFBs are glued to the panels.

3.1 Wiring Double Sided Panels

The wiring of the chamber is done winding directly around the honeycomb panels. In this way symmetrically loaded panels with wire planes on both sides are produced. The panel is

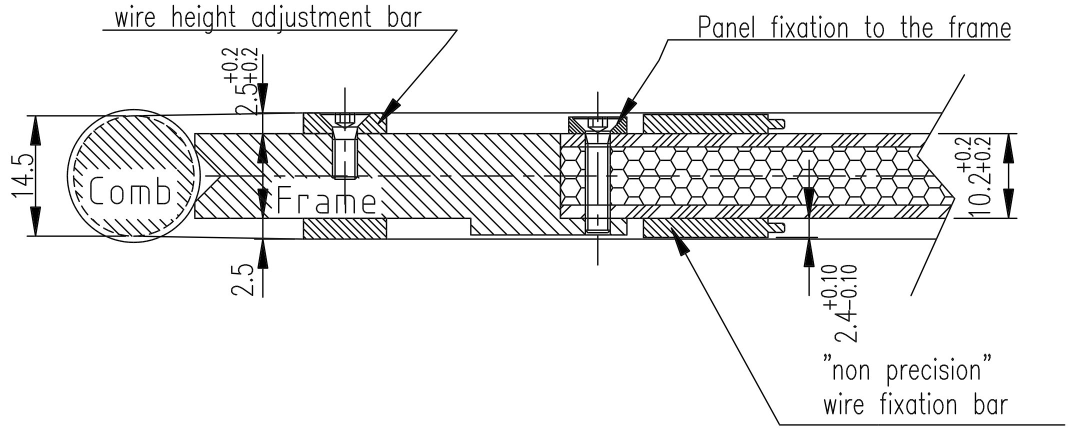

Figure 11 Schematic drawing of the frame cross section.

fixed to a rigid frame where the positioning combs are mounted. A schematic drawing of a cross section of this frame is shown in Figure 11. To achieve the required precision, the wiring method separates the two key parameters: the wire spacing is determined by the combs while the anode to cathode distance by the adjustment bars.

- **Threaded comb:** The threaded comb has a diameter of 15 mm and was machined in a precise way to have a thread path distance of 1.5 mm, which determines the wire spacing. The groove depth is of about 0.25 mm. In this way the inner diameter of the combs is smaller than the distance between the two wire planes.

- **Adjustment bars:** The wire height with respect to the cathode plane is adjusted by precision bars mounted to the frame. On one side, the bars are fixed, and on the other, they can be adjusted depending on the panel thickness to achieve a wire to cathode plane distance of 2.5 mm.

Once a frame is wired, it can be taken away from the winding machine to have the wires glued and soldered. This parallel production procedure separates the three most important and time consuming steps of the chamber construction.

The wiring procedure was tested for a detector panel. In Figure 12 a picture of the frame is shown where one can see the combs mounted to the long sides of it. As a first step, the precision of the combs were tested by wiring it alone without the panel and measuring the distance between the wires. At this point, 200 wires were measured under a microscope, which provides a resolution of 10 microns. The average pitch measured was 1.5 mm with an RMS of 10 microns. The next step was to test the effect of friction on the wire spacing precision. For this purpose, the panel was mounted on the frame and a metal bar was fixed to the wire fixation bar in order to simulate the adjustment bar that regulates the wire height. In Figure 13 one can see the detector panel mounted to the frame being wired on the winding machine. After wiring, the wire pitch was measured again. This time 200 wires of each side were measured giving an average pitch of 1.5 mm with an RMS of 14 microns. This comparison shows that the wire friction on the adjustment bars doesn't degrade the wire spacing precision, as can be seen in the plots of figure 14. The obtained RMS in both cases is well within the specifications of $\pm 40\mu$m.

The conclusions of these detailed tests is that the symmetric wiring method works very well for chambers smaller than 700 mm in length. For regions R1 and R2 of all muon stations this is

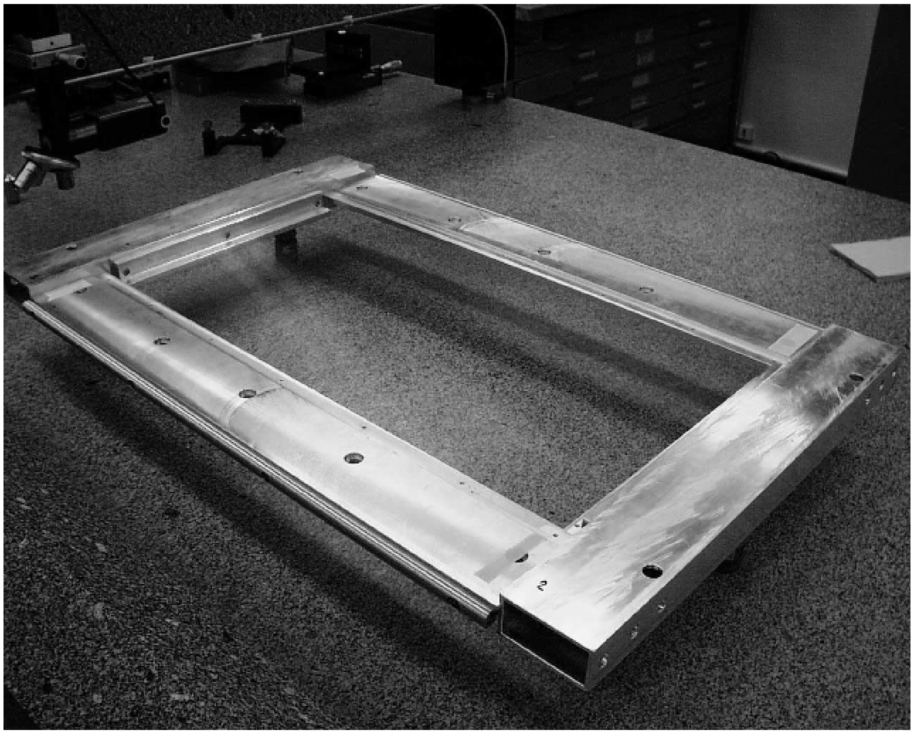

Figure 12 Wiring frame with the combs mounted on it.

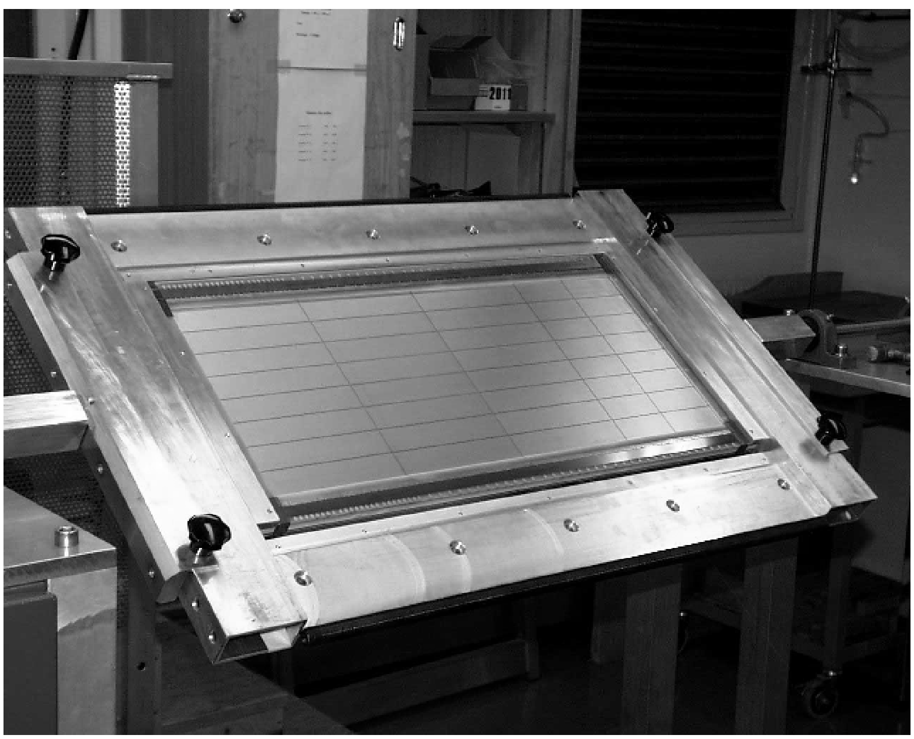

Figure 13 Wiring of a panel mounted to the aluminum frame.

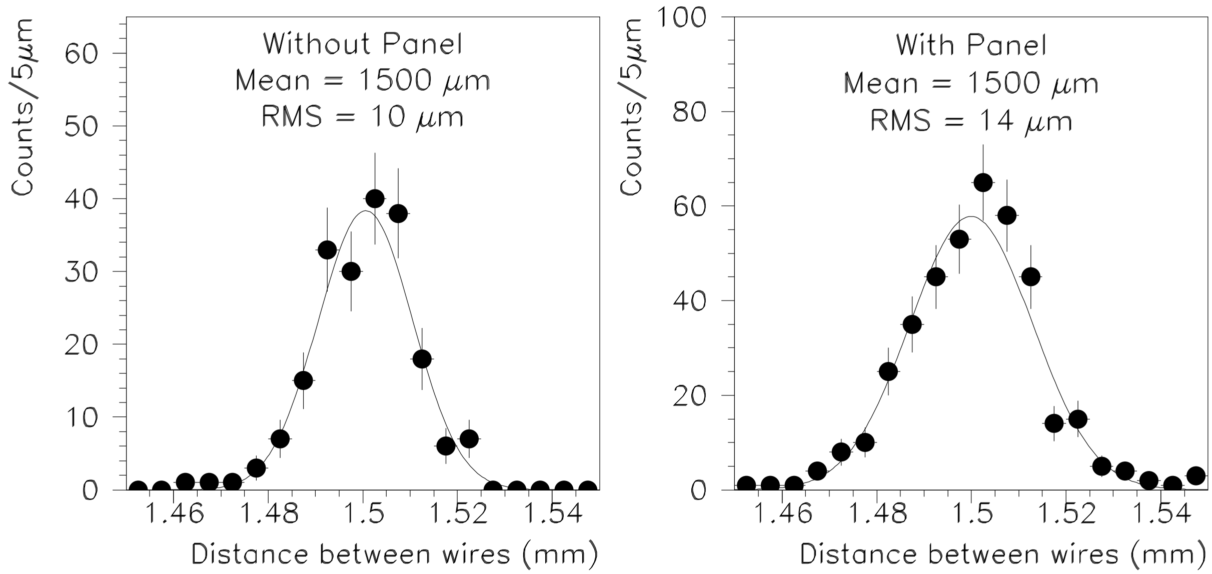

Figure 14 Distributions of the distance between the wires measured with the frame alone (left) and with the panel mounted to it (right).

a reliable and simple solution to ensure a trouble-free production of these chambers. For bigger chambers, the panels and the frame with the combs might sag differently during the wiring. To avoid this problem the panel should be fixed to the frame along its long side every 500 mm so that they have a common sag. In this way the anode to cathode distance can still be made precise. Another way to avoid the sagging is to wire the panels vertically.

3.2 Wiring Single Sided Panels

The production of panels with wires on a single side could be realized using the same winding machine, but with a different frame. A sketch of a possible frame can be seen in Figure 15 where two single sided panels are adjusted to the combs and wired in one go. Based on a calculation, no deflection of the panels is expected due to asymmetric load of 100 g/wire. Figure 16 shows the deflection as function of the FR4 thickness and of the distance between the FR4 foils. Tests done on both deflection and torsion of a panel wired in this way confirmed this result. The wiring guidelines are the same as mentioned in the previous section. For small chambers, the system is rigid. However, for the longer ones, a different sag of the panels with respect to the combs is present and a method of fixing them together over the long side is needed.

Studies are also ongoing to increase the number of single gaps to be wired in one process to eight planes, as shown in Figure 17. However, in this case the machine gets more complicated. The possibility of gluing and soldering on the same machine is under evaluation, although the possibility of having a production line with parallel procedures is lost.

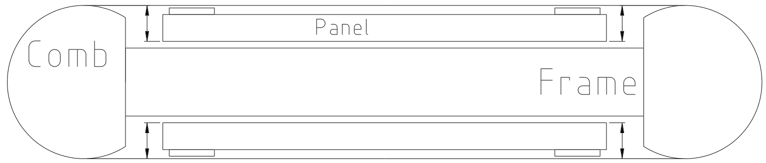

Figure 15 Sketch of a frame to wire two single sided panels together.

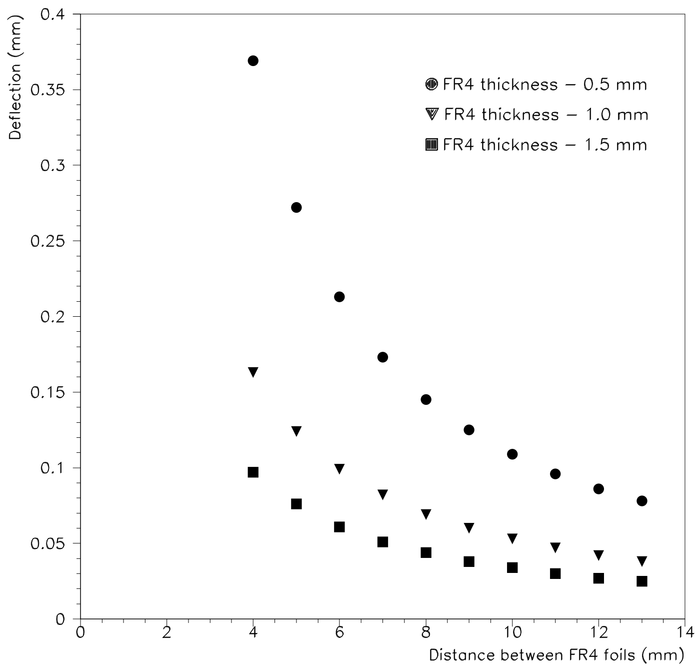

Figure 16 Maximal deflection of a panel with asymmetric load.

3.3 Glueing

The wires are glued to the wire fixation bars before soldering. This procedure guarantees that the wires are kept in place with a fixed height with respect to the cathode plane. The gluing also keeps the wire tension to its nominal value. The glue to be used is Adekit A145 which takes 24 hours to fully polymerize at room temparture.

3.4 Soldering

One of the cleanest soldering methods is the use of a laser beam. Due to the large number of soldering involved in the construction of LHCb MWPCs ($\approx 5 \times 10^6$), the use of an automated and reliable method is mandatory.

A test system was setup to study the realization of an automatic soldering station. The light source used was a diode pumped laser [2].

The setup consists of a stepping motor, of an endless screw and a slit on which the head of

[2]Model Violino from Laservall s.p.a., see www.laservall.com for further details.

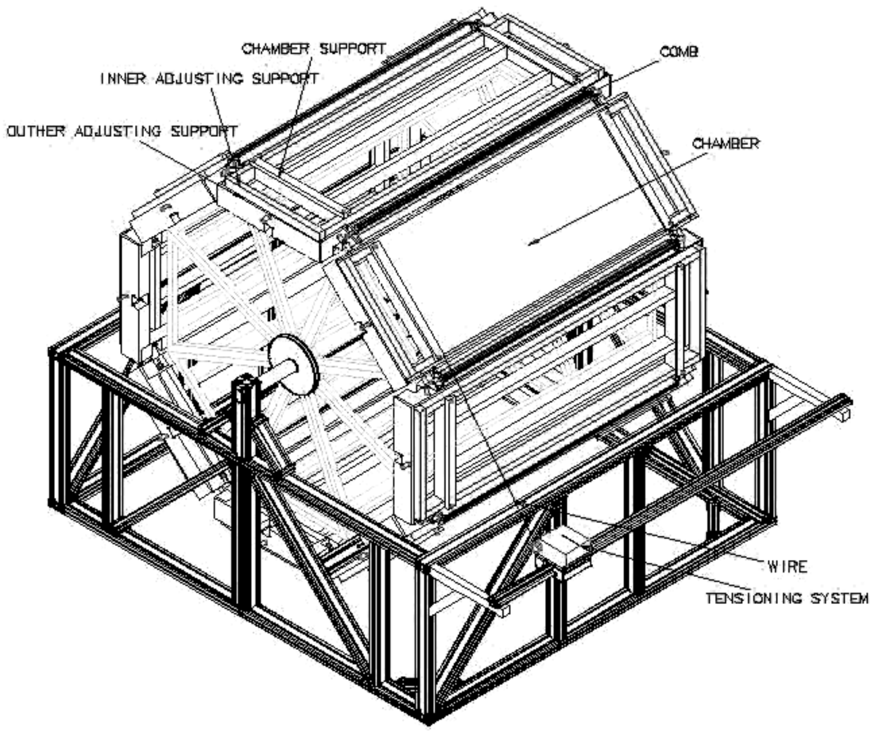

Figure 17 Concept of a machine to wire eight single panels in one process.

the laser is mounted, together with a solder dispenser system (see Figure 18). The solder wire used was a special alloy provided by Almit (KR-19 SH-RMA, 180^{o}C working point) with low flux content. The global time for the complete soldering of one wire and the positioning of the head to the next trace is about 2s.

The laser power was used at 60% of its maximal power (60 W). The study of the optimisation of this parameter is still ongoing, as well as the determination of the optimal amount of solder wire to be provided.

The result of soldering is very clean (no flux around, as shown in Figure 19) and the control of local heat is very good. The wire suffers less heat stress with respect to conventional techniques.

To become fully operational, the system has still to be upgraded in the following parts:

- Installation of a diode light guide to provide a reference point (the laser light is invisible);
- Better mechanical positioning of the wire fixation bar;
- Modifications to the solder wire dispenser to have a more precise control of its amount;
- Optical control of the head positioning. The possibility of using a camera to check the quality of the soldering is under study.

Using a conservative value of 3s for the soldering of one wire and assuming that the final setup will be equipped with 2 laser heads, we can evaluate the time needed for the soldering of the MWPCs. Considering only the largest chambers one has for instance:

Muon station 1, Region R4	491K wires (192 chambers)	410 hours
Muon station 2, Region R4	615K wires (192 chambers)	513 hours
Muon station 3, Region R4	664K wires (192 chambers)	553 hours

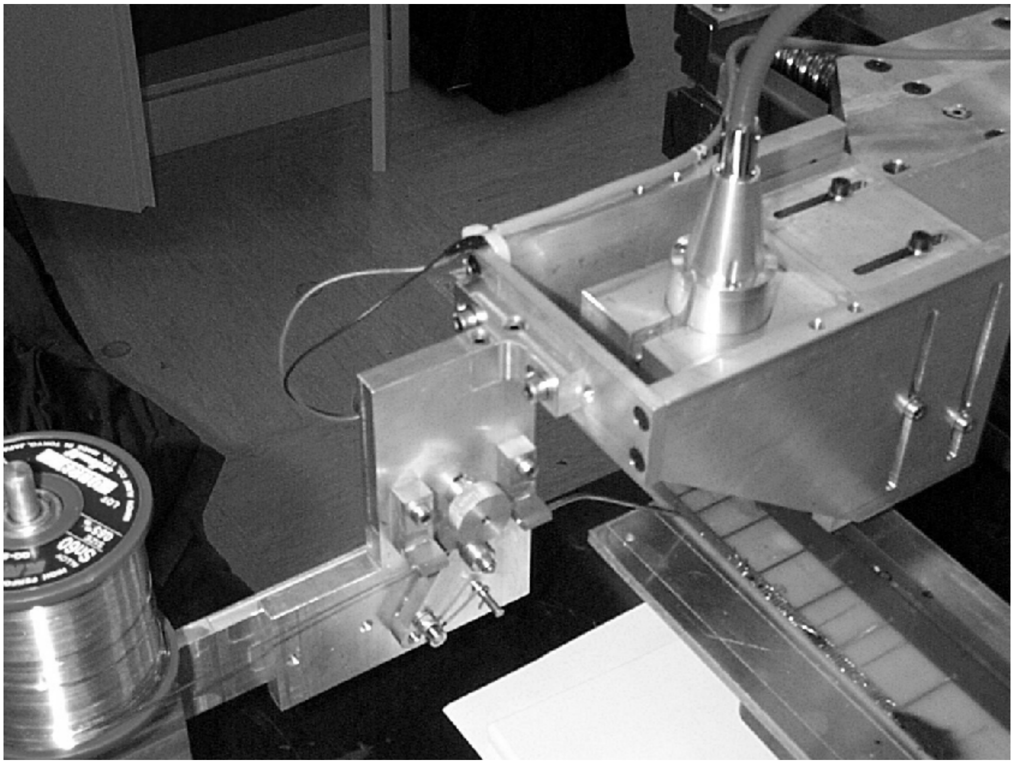

Figure 18 The laser soldering and the solder dispenser.

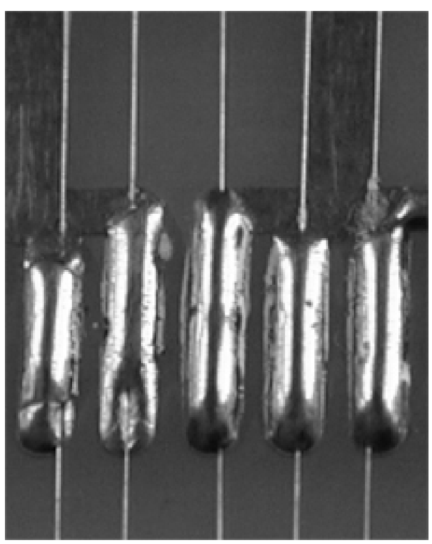

Figure 19 30 μm wires soldered on the traces.

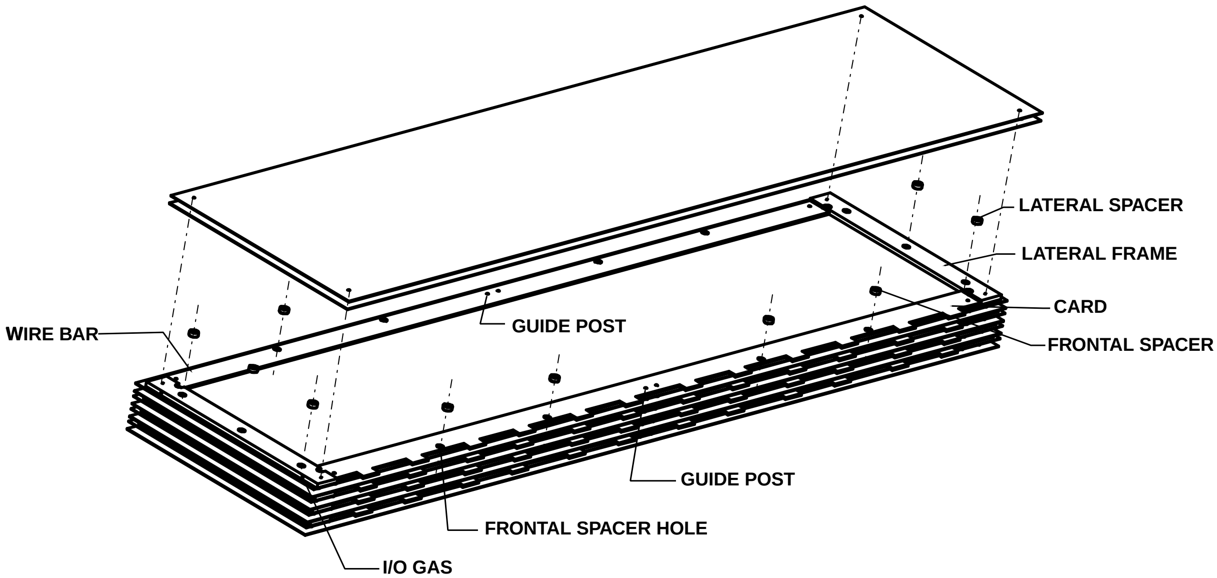

Figure 20 A sketch of the chamber assembly.

For the whole detector the total time for wire soldering would be 2100 hours. This number does not include the time spent for the layer setting up and for the needed checks. This time should be strictly proportional to the number of chambers. A single trained technician should be able to controls this phase of the chamber production.

3.5 Final Assembly

To proceed with the final assembly of the chamber, five panels should be ready: two double sided wired panels and three ground panels (or four single sided wired panels and one ground panel). All the panels are already equipped with side bars, wire fixation bars and gap bars. In the side bars the gas inlets/outlets for each gap are mounted. The cylindrical precision spacers are inserted now in the foreseen holes around the chamber and the panels are assembled making use of the jigs at the four corners. For the final closing of the chambers the five panels are kept together with screws. The leak tightness is obtained by gluing the five panels together with epoxy glue.

4 Electrical Layout

Several constraints determine the location of the readout electronics:

- Minimisation of dead space at the chamber border;
- Density of channels in inner regions;
- Space problems due to the proximity to the beam pipe in region R1;
- Connectivity requests due to logic ORs on FE-electronics cards.

Table 4 Space requirements for the chambers' border regions.

Details	
Wire fixation bars (top and bottom)	≈ 30 mm
Gap bars (side)	≈ 20 mm
Gas connection side	≈ 30 mm
HV part (HV bus, R, C)	≈ 35 mm
Cathode readout (bottom/side)	≈ 20 mm
SP board,FE board, Connector	≈ 20 mm
Sums	
Top with anode/cathode readout	85 mm
Bottom with cathode readout	70 mm
Bottom with no readout	35 mm
Side with no readout	50 mm
Side with cathode readout	60 mm

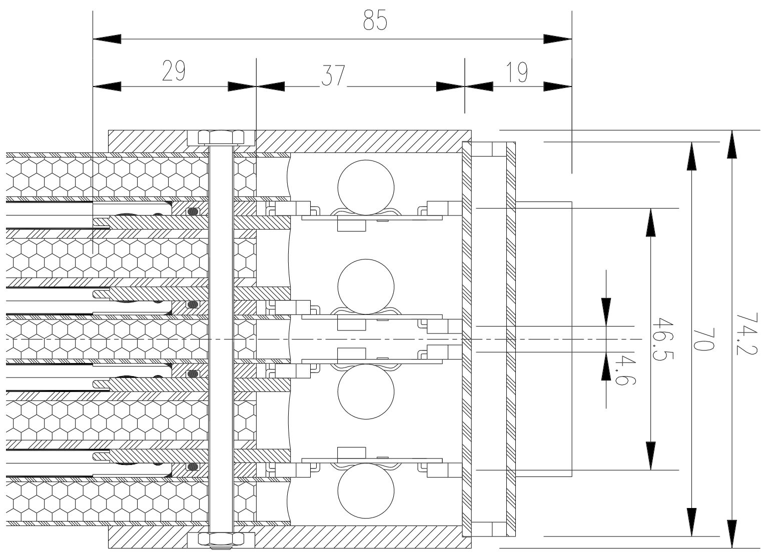

Figure 21 Schematic configuration of readout electronics of MWPC in the muon system.

A detailed study of these combinations for the various stations and regions lead to the scheme shown in Figure 21.

The border region of the chambers have the space requirements summarized in Table 4. These parameters ensure sufficient space between the chambers for the routing of cables for readout, high and low voltage, and gas pipes. Table 5 summarizes the readout configuration in each station and region, the full size of chambers and the vertical space available between chambers.

4.1 HV-interface

The HV-connection is realized by interface cards which carry the loading resistors and the decoupling capacitors. The ORs of wire pads from different layers and a large amount of ground connections to ensure as much as possible the reduction of electronic noise (see Figures 22).

Table 5 Readout scheme for the various stations and regions with the required space and the space left vertically between chambers. Legend: AW-RO: Anode wire readout; CP-RO: Cathode pad readout; t&b: top and bottom.

	Station 1	Station 2	Station 3	Station 4	Station 5
Region 1		top: AW-RO	top: AW-RO		
		side: CP-RO	side: CP-RO	side: CP-RO	side: CP-RO
Chamber size:		$42 \times 37\ \mathrm{cm}^2$	$44.5 \times 39\ \mathrm{cm}^2$	$47 \times 41\ \mathrm{cm}^2$	$49 \times 43\ \mathrm{cm}^2$
Free space:		12 cm	15 cm	17 cm	18.8 cm
Region 2		top: AW-RO	top: AW-RO		
		side: CP-RO	side: CP-RO	bot.: CP-RO	bot.: CP-RO
Chamber size:		$72 \times 37\ \mathrm{cm}^2$	$77 \times 39\ \mathrm{cm}^2$	$80 \times 44.5\ \mathrm{cm}^2$	$84.5 \times 46.5\ \mathrm{cm}^2$
Free space:		12 cm	15 cm	13.5 cm	15.3 cm
Region 3	t&b: CP-RO	t&b: CP-RO	t&b: CP-RO		
Chamber size:	$96 \times 33.5\ \mathrm{cm}^2$	$130 \times 38.5\ \mathrm{cm}^2$	$140 \times 42.5\ \mathrm{cm}^2$		
Free space:	6.5 cm	11.5 cm	13.5 cm		
Region 4	top: AW-RO	side: AW-RO	top: AW-RO		
Chamber size:	$96 \times 32\ \mathrm{cm}^2$	$130 \times 37\ \mathrm{cm}^2$	$140 \times 39\ \mathrm{cm}^2$		
Free space:	8 cm	1 cm3	15 cm		

Samples of these cards will be tested in real configurations with existing wire chamber prototypes to check the validity of this solution. The value of the decoupling capacitor should be much larger than the capacity of the group of wires connected to it. This ensures a low impedance to ground or to the amplifier. A value of 1nF satisfies this condition in all cases.

The upper band on the HV-loading resistor is given by the maximal allowed voltage drop, while the lower limit is set by the introduced parallel noise. The baseline choice is 100 $\mathrm{k}\Omega$.

4.2 FE-Interface

The FE-electronics will be implemented in two stages; the first stage as a spark protection board (SPB) and the second as the Amplifier-Shaper-discriminator (ASD) chip board (ACB). The ACB is mounted parallel to and immediately above the SPB. This design limits the distance the signals must propogate from the chamber. The dimensions for these boards are given by the thickness of the chamber (70 mm) (cf. Figure 21 and the maximal allowed space around the chambers (50 mm). The 50 mm are determined by region 1R, where the highest granularity of readout channels occur. Each board receives the signals of 8 readout channels from each double gap, in total 16 channels.

The SPB will be a 50 x 70 mm^2 two layer board that contains a system of resistors and diodes for each channel designed to limit the voltage in the event of a spark or discharge. The design uses a two stage double diode scheme: the first resistor is 8.2 Ω connected to two diodes [3] and a second resistor of 5 Ω was also connected to two diodes [2]. This design fully protected the readout channels during measurements up to 3.6 kV on the chamber and from discharges of a 1 nF capaciter. During tests no channel became damaged.

[3] BA V99

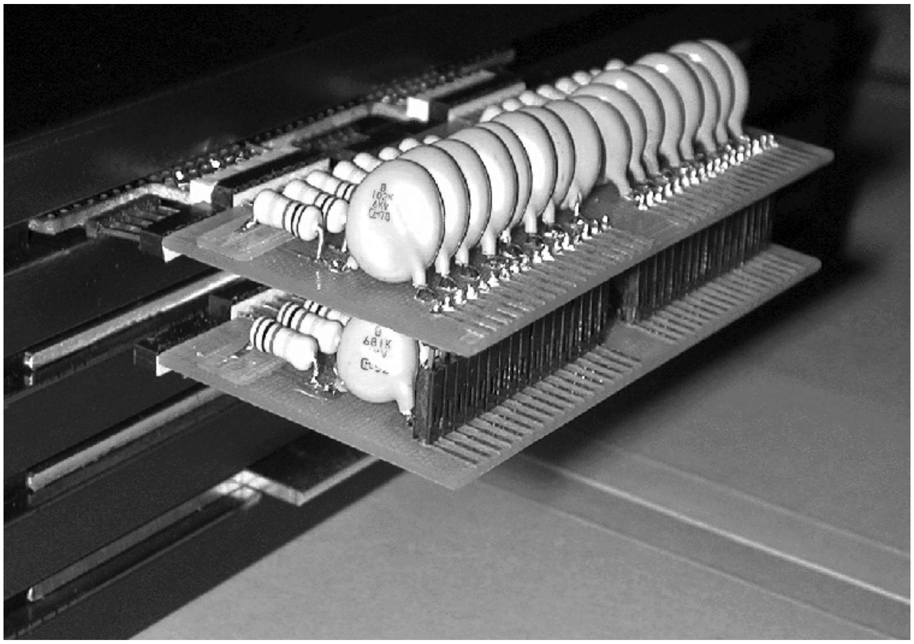

Figure 22 A photo of the prototype of the HV interface card for the M2R1 chamber.

The ACB is a 50x 70 mm^2 4 layer PCB containing two ASD chips and the so called DIALOG chip [5], which provides some basic logics and diagnostic functions.

4.3 Cooling of Electronics

The inner regions of the Muon System are characterised by a large amount of electronics located in a small space, in particular in region 1 of stations M2 and M3 where each chamber contains 224 readout channels. A rough estimation of the dissipated power has been performed in these cases. The box containing the chamber and the electronics is considered to be closed, with thermal contact (copper) only along the outer perimeter, while the front and rear faces are considered insulating. The copper closure is used to shield from external noise the electronics inside the box. A nominal consumption of 50 mW/channel has been assumed (ASDQ case). To this number the consumption of OR electronics and the presence of service elements (local regulators, controls, etc.) should be added. Up to now this addition is not quantified and therefore not considered in the evaluation. Using the approximate formula dT = $900\times$(P/S)$^{0.8}$ where dT is the internal thermal gradient (^{o}C), P is the total dissipated power in the box (W) and S the surface available for heat exchange (cm^2), it turns out that the inner chambers are subject to a large increase of temperature, that makes the operation of electronics unreliable (dT up to 30^{o}C). To overcome this problem, several possibilities can be envisaged:

- Artificially increase the surface of the copper shield;
- Pumping fresh gas through the box with a simple plastic pipe network;
- Cooling the copper shield. In this case a better thermal contact between cards and the shield should be foreseen.

All these options are under study, although a better understanding of the problem will come from a test with a real box, which will be done in the near future. A more realistic estimation of power consumption will be available then.

5 Quality Tests

Quality tests of the individual chamber components and for the assembled chamber are foreseen. The key items to be checked during chamber construction are the following:

- Panel planarity, which can be verified on samples with a proper apparatus;
- Wire quality, with optical inspection and tests of mechanical properties on samples;
- Soldering quality: due to the large amount, a semi-automatic procedure should be foreseen. This test should also include electrical continuity.
- wire tension checks: An interesting method to control the wire tension of an entire wire pad is to induce mechanical oscillations by passing an A.C. current through it while immersing the system in a magnetic field[6]. Being a non-contact and an easily automatized method, itis adapted to our needs. In order to test this method a 1.5 mm pitch pad of 4 wires (3 with 50 g tension and one with 60 g) was prepared at 2.5 mm from a cathode plane. From a FFT analysis of the induced oscillation, showed in Figure 23, it is possible to determine the tension within a 3 gf precision, which is a value well bellow the allowed tolerance of 10 g;
- Wire positioning, to be verified on a small set of points on each wire plane;
- Gas tightness, to be verified using standard procedures such as applying a small underpressure to the chamber in an He-bag and looking for possible leaks;
- HV training and tests. This part will be the most important one because it should certify the quality of the production from each centre. A ”good” chamber should be able to sustain a certain value of HV well inside the operation plateau for a certain amount of hours, after some training has been performed using an automated procedure.

Afterwards the chamber will be inspected for the uniformity in response. A very efficient method is to perform a scan of the wire plane with a calibrated source, checking that the counting rates of pads is uniform through all the chamber. In addition, a complete test with cosmic rays to determine efficiency plateau and time resolution will be performed. As far as possible, this tests will be done with final electronics.

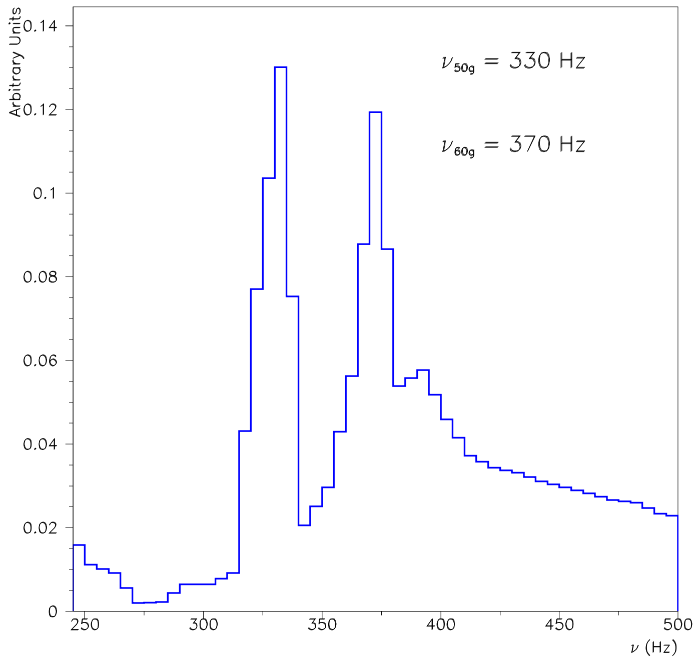

Figure 23 Result of a FFT analysis of the induced oscillations in a pad of wires. The first peak, at 330 Hz, corresponds to the oscillations of the three wires submitted to a 50 gf tension and the second one, at 370 Hz, to the 60 gf wire.

6 Costs Breakdown

Item	Unit	Number	Cost (CHF)/unit	Cost+20% (CHF)
Wire	km	1215	120	174960
Wire fixation bars	0.5 m	14560	5	87360
Side bars	0.3 m	5683	2	13639
Panels	m^2	250	1300	390000
Spec. Cath.(R1,R2)	m^2	200	380	91200
HV boards	1	13000	7	109200
Capacitors	1	100000	0.2	24000
HV GND Conn.	16	31250	0.5	18750
Jig spacers	1	25000	0.2	6000
Total				**915109**

7 Construction Schedule

An overview of the project plan is given in Figure 24. After finalization of the engineering design, the "module 0" of the chambers in the various regions should be build and the production lines should be set up. In case panels based on honeycomb should be used, the panel preparation is rather time consuming (even if several panels are prepared in parallel) and should therefore start about 1/2 year in advance of the chamber production. It is foreseen to have four centers

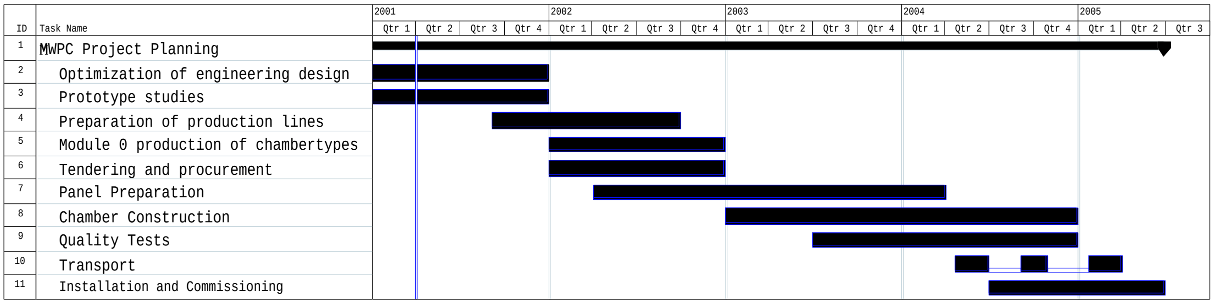

Figure 24 A sketch of the chamber assembly.

for chamber construction, assembling and testing. The time estimated for chamber construction is 2 years. This means that each production center should produce a fully tested chamber in 2 working days. Chamber installation and commissioning of the muon system should start in the second half of 2004 and take about 1 year.

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