9 Services

9.1 Low voltage power distribution

The TRD electronics is located on the readout plane of each chamber. Low voltage has to be distributed to these areas of the detector to power the multichip modules (MCM), see Chapter 5. Two possible solutions are being considered for supplying power to the detector front-end electronics, inside the L3 magnet:

- power supplies located outside the magnet, in the experimental hall, delivering the required voltage and current directly to the load. In this case the power cable conductor cross-section must be large enough to limit the voltage drop, and cable bulk as well as copper conductor weight are major concerns;

- DC-to-DC converters placed inside the magnet and close to the load. In this case the cross-section of the input power cables can be significantly reduced. However the converters must be able to operate in the magnetic field up to 0.5 T, either by shielding or by using a special design. The possible effects of radiated or conducted noise from the switching supplies need to be understood. Moreover, the reliability constraints are increased since access for maintenance is very limited.

In both cases low-drop voltage regulators are installed on the electronics boards. The first solution has been worked out in detail and is presented here. The second one is being investigated.

9.1.1 Requirements

The low voltage system must deliver a large current (about $\sim$18kA in total for Pb-Pb collisions) at 3.3 V and 2.5 V. For noise isolation, the power will be distributed separately for the preamplifier/shaper (analog-1), ADC/filter (analog-2) and digital parts (digital-1). Low-drop linear regulators installed just before the electronics are used to regulate the bias voltage. The power supply requirements, expected currents and resulting power are summarized in Table 9.1. The numbers are calculated using 0.35 μm technology for the preamplifier/shaper and 0.25 μm technology for the ADC and digital components, see Chapter 5.

Table 9.1: Power supply requirements of the electronics. V: required voltage. P_{ch}: Power consumption per channel. P^{total} and I^{total}: Total power and total current required by the electronics. P_{reg}^{total}: Total power dissipated in the low-drop linear regulators. The numbers are based on 1.16×10^6 channels and the expected trigger rates for Pb-Pb and p-p collisions.

	V(V)	P_{ch}(mW)	P^{total}(kW)	I^{total}(A)	$P_{reg}{}^{total}$(kW)
analog-1(PASA)	3.3 V	10	11.6	3503	1.4
analog-2(ADC,filter)	2.5 V	27.4	31.7	12690	5.2
digital-1^{Pb-Pb}	2.5 V	1.1	1.2	1515	0.6
digital-1^{p-p}	2.5 V	11.9	13.7	10139	4.2

For the digital part the power consumption and required currents depend on the trigger rate, the numbers for both Pb-Pb collisions (10 kHz and 1 kHz L1A, see Section 1.2) and p-p collisions (150 kHz and 5 kHz L1A) are quoted but the p-p values are taken for the design. The power in the analog parts is constant. For example, doubling the trigger rate increases the total power consumption only by 3% but the required current in the digital-1 supply by 68%. The maximum power consumption is 49.3 mW/channel for p-p collisions. Taking into account the total amount of channels of 1.16×10^6 and the power dissipated in the regulators, the total power dissipated by the electronics is 67.8 kW (51.7 kW for Pb-Pb collisions).

9.1.2 Low voltage power supplies and cables

The low voltage system will be subdivided into independent low voltage channels. The actual number of LV channels is a compromise between cost and performance. Each of them will power a complete layer, that corresponds to 5 chambers. This means a total of 3×108 cables (analog-1, analog-2 and digital-1) and their respective return lines. The power supplies will be located outside the L3 magnet (UX25 cavern) on both sides of the detector (RB24 and RB26) in an area not accessible during LHC operation. In this scenario a cable length of about 31 m is needed, 15 m from the power supplies to the magnet and 16 m from the magnet up to the distributing ring and all the layer length. The cables will pass through the L3 magnet doors, at about half the height of the detector.

Table 9.2: Characteristics of each cable (c) for a low voltage system based on 108 channels and trigger rate as corresponding to p-p collisions. I_c: Current carried in each cable. S and L_c: Cross section and length of each cable. W_c: Cable weight, R_c: Cable resistance. P_c^{total}: Total power dissipated on the cables.

	V(V)	I_c(A)	S × L_c (mm^2×m)	W_c(kg)	R_c(mΩ)	P_c^{total}(kW)
analog-1	4.3 V	33	(58×15+31×16)	12.3	17.7	4.2
analog-2	3.5 V	121	(211×15+113×16)	44.6	4.9	15.4
digital-1^{Pb-Pb}	3.5 V	14	(25×15+14×16)	5.3	41	1.8
digital-1^{p-p}	3.5 V	96	(169×15+90×16)	35.6	6.1	12.2

The cable characteristics, summarized in Table 9.2, are selected as a compromise between voltage drop, power dissipation and cross section. The p-p scenario has been used for the design. Cables are designed with two widths, one part of 15 m length from the power supplies up to the L3 magnet. This selection is done to minimize the power dissipation in a region where there is no space limitation. The other part, of 16 m length, from the magnet doors to the detectors where the width is reduced to the half to fit into the available space (see Fig. 9.1). With this design the voltage drop in the cables is 0.59 V and the total surface occupied for the bare cables is 505 cm^2. The total weight of such Cu cables is about 19 t. In addition to the 505 cm^2 some space has to be considered for isolation and cooling of the cables, since the total power dissipated on the cables is 21.4 kW for Pb-Pb collisions and 31.8 kW for p-p collisions (see Table 9.2). If we account for a voltage drop of 0.59 V along the cable and of 0.4 V for the local regulation, the power supplies should provide 4.3 V and 3.5 V, respectively.

A schematic layout of the low voltage system is shown in Fig. 9.1. The power supplies are floating. The return lines are connected to the front-end detector ground. The low voltage system as previously described presents some disadvantages with regard to cable cost and heat losses in the cables, and also to the space occupied by the cables passing through the L3 magnet doors. Therefore, an alternative scheme based on delivering the power at a higher voltage (48 V) and converting it to the required one very close to the detector is also under consideration. Inside the L3 magnet in the distributing ring two types of Vicor DC-to-DC converters (V48B3V3C150A and V48A3V3C264A, for example) could be used for voltage conversion. It still needs to be proven that these devices can work inside the L3 magnet. Some calculations [1] show that a magnetic shield of 2-3 cm will be needed to have acceptable attenuation of magnetic field densities of 0.4 T. As the amount of converters is not negligible, the distortions created inside the L3 magnet need to be studied. On the other hand, other companies like CAEN are also developing DC-to-DC converters which could in principle work in magnetic fields. Recently, a prototype

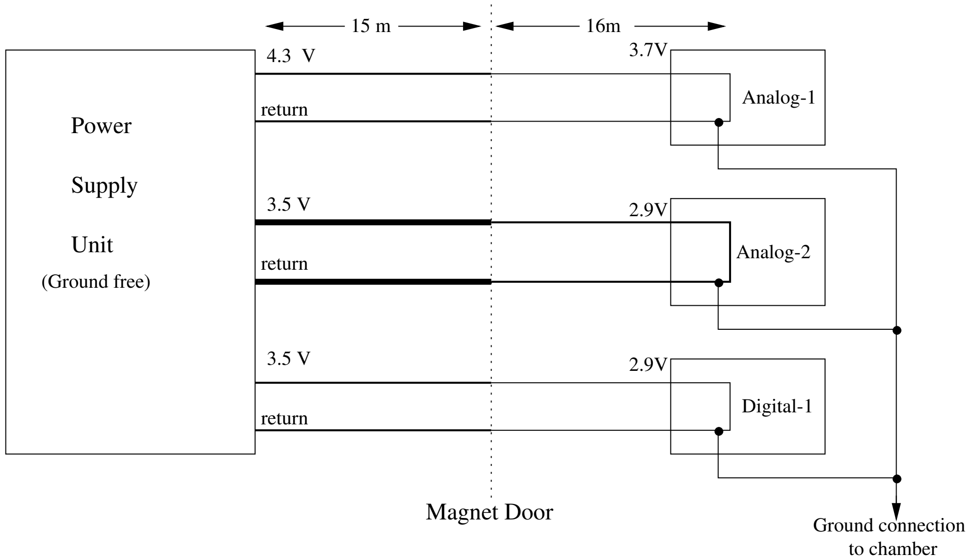

Figure 9.1: Connection of low voltage power supplies to electronics

has been tested at CERN showing a good behaviour up to 0.18 T. Higher values of magnetic field were not available during the test. A second test in a magnetic field up to 1 T has also been done. The device showed a behaviour according to specifications up to 0.5 T. After proper operation at 1 T some components failed. As the principle of operation of the prototype is proven to work, the company plans to work on improving its reliability.

9.1.3 Layout

9.1.3.1 From power supplies to each chamber

The low voltage power cables will come from the power supplies to both sides of the detector through the L3 magnet doors. The cable configuration through the magnet doors can be seen in Fig. 16.2. The cables will have a connector at the distributing ring to be able to disconnect from the supermodule for maintenance. A flexible cable might be forseen there.

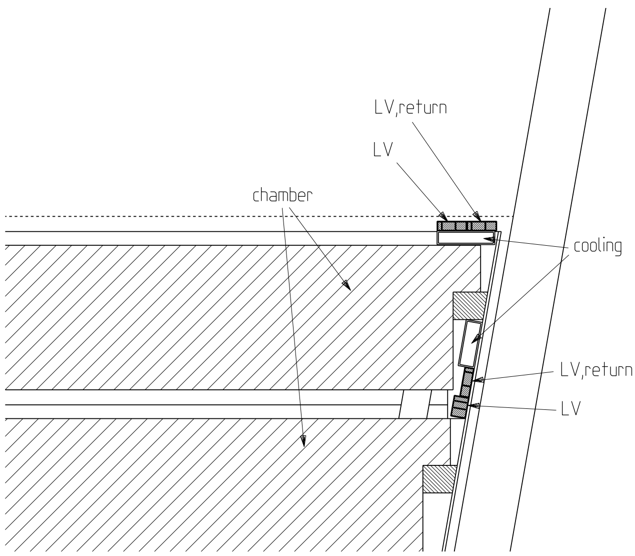

Figure 9.2: Routing of the low voltage power cables along a layer.

In order to avoid current loops in the detector the power cables and their respective return lines will be routed in the same side of the layer. In addition, the chamber readout PCB is split into two φ sections, the power to each layer will come from both φ sides. To keep the number of LV channels constant at 108, each cable will be split into two at the level of the distributing ring. The space between the chamber holder and the supermodule case will be use to route the cables along *z* in each layer, see Fig. 9.2. The cables will supply the voltage to the chamber underneath. This part of the cable also needs cooling.

9.1.3.2 Inside the chamber

Depending on the chamber position and the layer the MCMs in a chamber are organized in rows of 4+4 MCM each making a total of up to 76 rows per layer. Each cable will have up to 76 connections consisting of a low-drop voltage regulator and 4 MCMs connected in series. The 4 MCMs will also be connected in series for the return line cable. The power distribution scheme inside a chamber is depicted in Fig. 9.3.

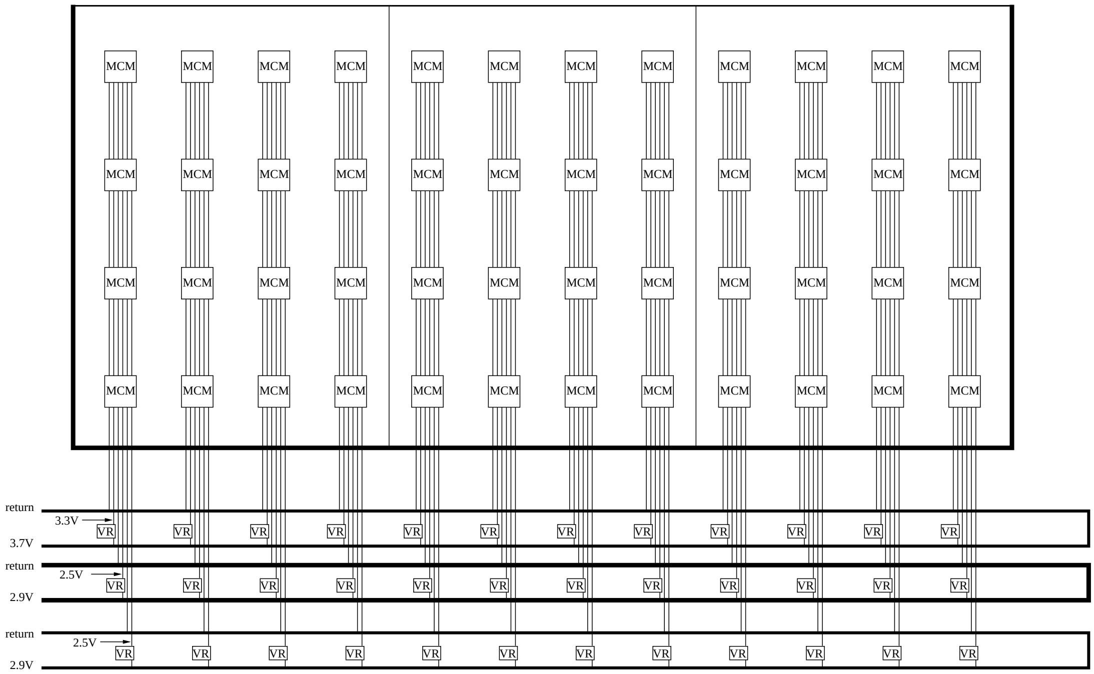

Figure 9.3: Routing of the low voltage power cables in the readout plane (only half chamber is depicted) to power each of the MCM rows. The cables along a layer are also shown.

Each of the MCM rows in the chamber will receive the necessary power from the low voltage power cables running along *z* on both sides of the layer. Cables up to 0.61 m length for the largest chamber will be necessary. Assuming that 20% of the chamber plane is covered by Cu, the width of the power lines could extend up to 0.8 mm, 4.0 mm and 2.7 mm for analog-1, analog-2 and digital, respectively, with a standard thickness of 34 μm. The return lines are designed with the same parameters. With these characteristics a voltage drop of 113 mV, 82 mV and 97 mV can be expected in the worst case. The power dissipated in these traces will be 27.7 W per layer for Pb-Pb collisions (45.9 W per layer for p-p collisions) , i.e. adding 4.7% to the total heat dissipated in a layer.

9.2 High voltage power distribution for drift field

The high voltage distribution for the drift field will be done according to chambers. The total number of HV channels is 540. Each channel should be independent in terms of voltage setting, current limit, ramp up and down, switching on and off and monitoring of current and voltage.

9.2.1 Requirements

In order to create the necessary drift field a high voltage of -2.1 kV is needed (See Chapter 4). The ripple has to be kept smaller than 50 mV peak to peak and the stability should be better than 0.1% over 24 hours.

9.2.2 High voltage power supplies

The power supplies should be able to deliver up to -3.5 kV with a current of up to 500 μA/channel. These values contain already a safety margin compared to nominal running conditions. The high voltage power supplies will be positioned on both sides of the detector (RB24 and RB26) outside the L3 magnet in the UX25 cavern. A total length of about 60 m is anticipated between the high voltage power supplies and the detectors. A 42 Ω cable type HTC-50-1-1 (standard CERN) can be used (in accordance with IS23 regulations) from the power supplies to the detector. This HV cable is 3.30 mm in diameter, leading to a total cross section of 540×0.086 cm^2= 46.2 cm^2 for all 540 cables.

9.2.3 Layout

The cables will be grouped together, passed through the L3 magnet doors, and brought up to the distribution ring. A connector is foreseen there in order to be detachable from the detector for maintenance. The cables will then be separated in order to power the individual field cages, see Fig. 4.7. Consecutive φ-sectors will be powered from opposite sides of the magnet.

9.3 High voltage power distribution for readout chambers

The anode wire plane of each chamber will be supplied with HV independently. The total number of individual HV channels is 540. Such granularity is important in case of failure, because it reduces the affected area to one chamber.

9.3.1 Requirements

The anode wires need a voltage of around 1.7 kV in order to reach the required gas gain. (See Chapter 4). The ripple should be smaller than 50 mV peak to peak and the stability better than 0.1% over 24 hours.

9.3.2 High voltage power supplies

The power supplies should be able to deliver up to 2.5 kV with a maximum current of about 40 μA/channel. These numbers contain already a safety margin compared to nominal running conditions. The high voltage power supplies will be positioned on both sides (RB24 and RB26) of the detector outside the L3 magnet (UX25 cavern). A total length of about 60 m is anticipated between the high voltage power supplies and the detectors. A 42 Ω cable type HTC-50-1-1 (standard CERN) can be used (in accordance with IS23 regulations) from the power supplies to the detector. The diameter of this cable type is 3.30 mm, leading to an area of 540×0.086 cm^2= 46.2 cm^2.

9.3.3 Layout

The cables will be grouped together, passed through the L3 magnet doors, and brought up to the distribution ring. In order to be detachable from the detector a connector is foreseen there. The cables will then be separated in order to power the anode wire plane of each individual chamber. Consecutive φ-sectors will be powered from opposite sides of the magnet.

9.4 Cooling distribution

9.4.1 Requirements

The TRD cooling system needs to remove a large amount of heat (up to 76 kW for Pb-Pb collisions and up to 105 kW for p-p collisions). A large part of it, 64.1 kW and 86.7 kW respectively, are generated inside the supermodules by the front-end electronics and low voltage distribution inside the supermodules. This heat is dissipated over a large area $\sim$800 m^2. The 6 layers are separated by only about $\sim$4 mm. These factors determine the choice of the cooling agent to be demineralized water. Forced air cooling technique has also been considered for its obvious advantage of introducing no additional material within the TRD acceptance. Calculations have shown that effective cooling cannot be achieved with such an approach without applying prohibitively high air pressure on the cathode planes of the detectors. Moreover, the configuration of the TRD and other ALICE subsystems make it difficult to introduce an air supply duct of large cross-section required for the air flow. Water cooling will be free of these limitations and will provide effective cooling with relatively little material. The second generation Leakless Liquid Cooling System (LCS2) has been selected. This type of system has been successfully used by other experiments at CERN (CERES/NA45, NA49) and at BNL (STAR) and has been proposed for other LHC experiments as well (ALICE TPC, ATLAS calorimeter and CMS pixel detector) [2, 3].

9.4.2 Description of cooling system and layout

The scheme of the cooling system developed in collaboration with the CERN/ST/CV group is depicted in Fig. 9.4. The main parameters of the cooling system are described in Table 9.3.

Table 9.3: Main piping parameters of the cooling system based on the heat dissipation for Pb-Pb collisions. The pipe profile inside a supermodule along *z* is chosen to be rectangular to fit in the available space. The equivalent diameter assuming a cylindrical pipe is quoted.

	Number of pipes	Material	Inner diameter (mm)	Length (m)	Nominal flow	Pressure drop (mbar)
RB26 to L3 magnet	1	polyethylene	60	30	19.3 m^3/h	
return	1	polyethylene	60	30	19.3 m^3/h	
magnet to supermodules	18	polyethylene	20	15	1.1 m^3/h	
return	18	polyethylene	20	15	1.1 m^3/h	
supermodules to layers (along z)	108	inox	20	7	178.3 l/h	29
return	108	inox	20	7	178.3 l/h	29
layer to MCM	2736	Al	2	5.6	6.9 l/h	267

The cooling system will be positioned on one side of the detector (RB26) outside the L3 magnet (UX25 cavern). Each of the 18 sectors will be supplied and controlled independently. This scheme presents the advantage of easier regulation and control. Moreover, the pressure regulators used to maintain the pressure below the atmospheric can be positioned outside the magnet avoiding the use of special equipment. Flow regulators instead of pressure regulators might be considered. Each of the 18 circuits will supply cooling water to the 6 layers in a supermodule. The cooling liquid is kept in the storage tank

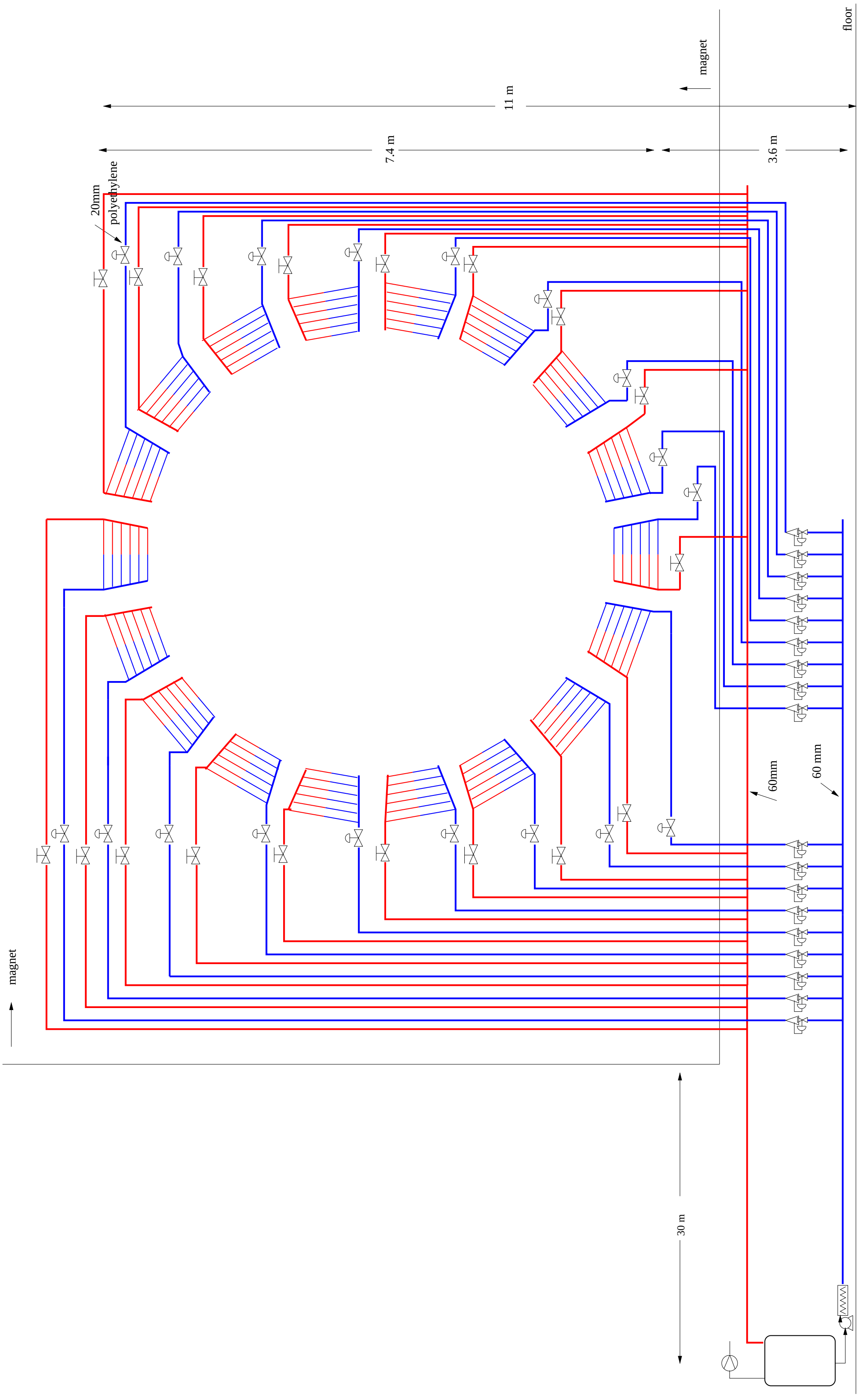

Figure 9.4: Water cooling system scheme based on sector distribution.

positioned at the lowest point of the system at a distance of about 30 m from the L3 magnet. The liquid is moved by a circulator pump into the heat exchanger cooled by chilled water from the CERN network. Two main pipes 60 mm diameter made of polyethylene, with cold and warm water respectively, bring the water from the tank to the base of the magnet and vice versa. From the base of the magnet 18 pipes of 20 mm diameter each pass through the magnet doors and bring the water to the sectors. On the return side the 18 pipes pass through the magnet doors and are collected together outside the magnet. In the present scheme, it is foreseen to provide the cold water in the lowest point of each sector and to collect the warm water on the highest point in order to have more homogeneous water flow in all pipes. Each circuit has a valve at the input and at the output at the level of the distributing ring to be detachable in case of maintenance. One of them is pneumatically controlled to be able to stop the water flow in case of problems during running time. At the input of the pressure regulators the pressure is above atmospheric pressure. The regulators adjust the pressure in the individual lines to a value that is below atmospheric pressure. They also guarantee that in all subsections of the cooling circuit a value below atmospheric pressure is maintained. Any leak in these lines and connections will not lead to a leak of cooling liquid. A vacuum pump in the return line sustains a pressure below atmospheric pressure and discharges any excess air collected.

9.4.2.1 Water distribution to the layer

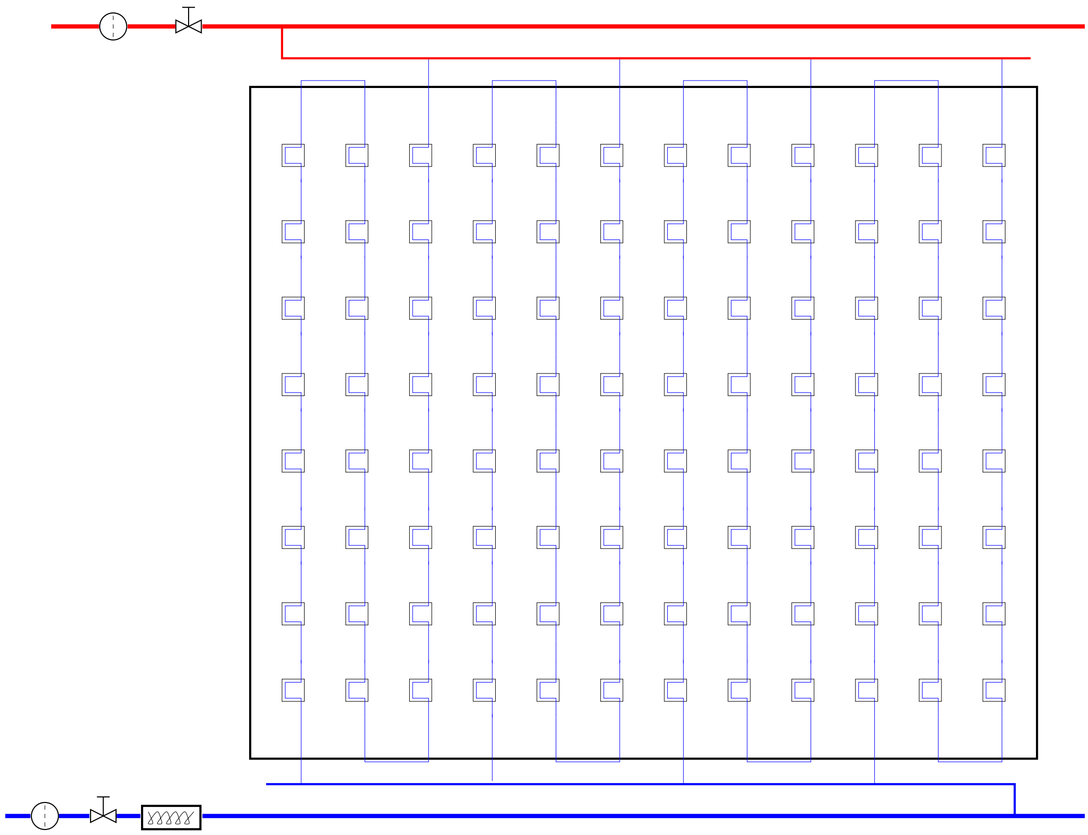

Figure 9.5: Main distribution of cooling water in a layer. For simplicity only one chamber with 12 rows is shown.

The layer subcircuit consist of 2 main rectangular pipes (20 mm equivalent diameter) along *z* made of stainless steel, see Fig. 9.2 and Fig. 9.5. Their function is to supply water to the individual pipes running in φ across the chamber where the heat sources are and to serve as a collector for the warm water. The flow in these pipes is turbulent. The pressure drop for a turbulent flow of 179.3 l/h (see below) in a straight pipe of 7 m is of about 29 mbar. The space between chambers and the supermodule casing will be used to route the cooling pipes, see Fig. 9.2. Each layer has a heater to regulate the water temperature and a filter to avoid impurities coming into the system. Each layer also has a manual valve to be able to close individual layers independently during tests. As the pressure drop along z is negligible with respect to the one across φ the water input and output can be on the same side.

9.4.2.2 Water distribution inside the layer

The readout boards will be designed such that the components radiating most of the heat (MCMs)will be aligned. Each MCM will be covered by a thin plate of Al for good thermal contact. An Al tube of 2 mm diameter will run across φ, to take away the heat produced in a row of MCMs (see Fig. 9.5). The path of the water pipe on the Al plate corresponds to aproximately three times its width in order to increase the heat transfer to the water. The water flow in these pipes will be 6.9 l/h, and the flow is laminar. Three rows will be connected together to have a large pressure drop in φ and to reduce the number of connectors. As the number of rows in a chamber is not a multiple of 3, rows of different chambers will be connected together. The temperature difference between input and output of the small pipes is 3 degrees for the flow of 6.9 l/h. However, as the warm and cold lines are inserted together the overall temperature gradient will be minimized. The total flow for a layer is 179.3 l/h corresponding to 19.3 m^3/h for the complete detector.

9.5 Gas distribution

The gas system has been described in Chapter 8. Therefore, only the relevant parameters from the services point of view will be mentioned here.

9.5.1 Layout

As already mentioned in Chapter 8, the hydrostatic pressure over the total height of the detector is 2.5 mbar. Since the detector working pressure is limited, for mechanical reasons, to 1 mbar, a subdivision of the full detector is necessary. Furthermore, the flow and pressure regulation must be done in each section independently. On the other hand, due to space limitations inside and around the L3 magnet, it is desirable to place as much hardware as possible in other areas. Taking into account these considerations gas is distributed through a 54-line manifold. Each line serves one set of 10 chambers -two layers back and forth in z-, and the pressure regulation sensor is placed at the outlet, thus being the only component inside the L3 magnet. All the other components will be located at the plug. Table 9.4 shows an overall view of the main piping parameters.

Table 9.4: Main piping parameters of the gas system.

	Number of pipes	Pipe diameter [mm]	Length [m]	Nominal flow [m^3/h]
SGX building to plug	1	73	90	5
Plug to RB26 side	54	4	100	0.1
RB26 side to plug	18	16	100	0.28
Plug SGX building	1	73	90	5

The feedthrough from chamber to chamber will be a short (3 cm) pipe with an inner diameter of 18 mm. The pressure regulation will be performed at the outlet of each sub-circuit (three per sector) by placing the pressure sensor close to the last chamber. Still inside the L3 magnet a 3-fold manifold will merge the lines from each sector into one 16 mm line. Therefore, a total of 18 outlet lines will run up to an accessible area at the plug, where the rest of the instruments for flow and pressure regulation will be installed. All of these circuits will route into the L3 magnet space from the RB26 side (the side of the muon arm).