SPECIFICATIONS OF A HIGH VOLTAGE SYSTEM PROTOTYPE FOR THE MDT AND TGC DETECTORS OF THE ATLAS MUON SPECTROMETER

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1. System description

The High Voltage system of the MDT and TGC detectors is spitted in two parts: the first generates the HV and resides in the electronics cavern USA15, the latter distributes the HV to the detector chambers and must reside in the experimental cavern, on the muon apparatus supports. Here, the crates containing the distribution boards are mounted in racks placed near the detectors, as shown in fig. 1.

The reason of this choice is due to the need of avoiding as much as possible the toroidal magnetic field and the radiation background for the HV generation electronics, whereas the relevant number of cables makes such a solution not feasible for the HV distribution electronics.

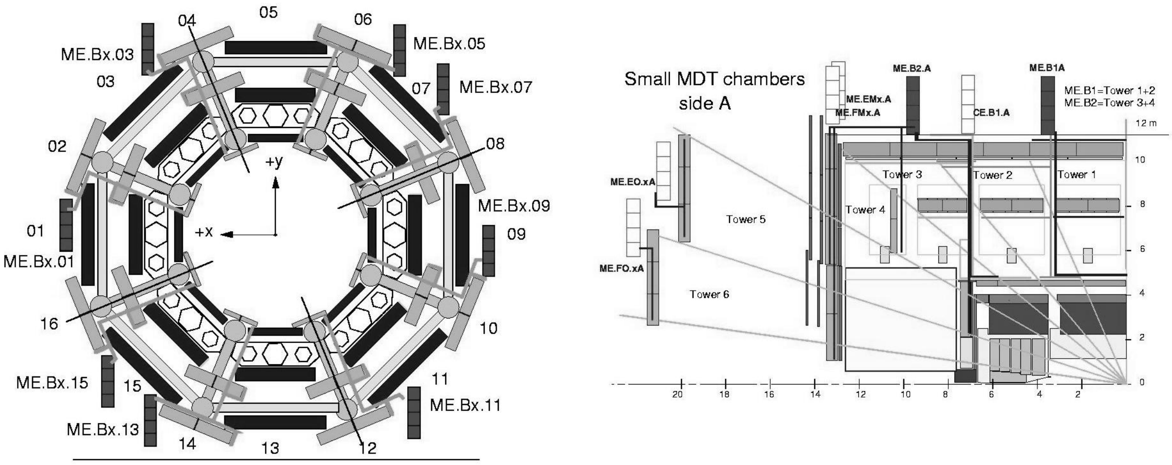

Fig. 1 – Conceptual position of the racks around the muon apparatus

The HV generation is composed of modules installed in specific application crates. They must supply a DC HV of 4 kV at 4 mA current.

The distribution boards are installed in industrial crates without power supplies and backplanes. The HV generators must supply the LV for the electronics of the distribution boards.

Three types of cables, roughly 100 m long, link the HV generators to the HV distributors: the HV cables, the LV cables and the communication cables.

The HV outputs of the HV distributors, 24 each one, are sent to the multilayers for the MDT, and to the wire chambers for the TGC. A different modularity, for example 16 HV outputs, could be foreseen for part of the TGC. The length of the connecting cables is of the order of few meters.
In fig. 2 the HV system block of the MDT detector, together with its connections, is sketched. For it, the required HV outputs channels are 2400. The HV system of the TGC detector is the same, replacing the multilayers with the wire chambers. For it, the required HV output channels are 3600.
The 24 HV outputs of the HV distributor are segmented in 4 independent sections. Each HV output consists of a voltage regulator, a current limiting and a voltage and current monitor.
The polarity of the HV inputs of the HV distributor is positive, but it must also accept a negative polarity, because a negative HV could be used for curing the MDT multilayers in case of early ageing. The curing current can be as high as 100 mA at 2 kV. In order to meet this requirement, a HV high current diode is connected in parallel to the regulator circuit. Fig. 3 shows the block diagram of the HV distributor.
The width of the HV distributors is very important, in order not to exceed the total number of racks foreseen for the HV system. For the MDT detector, 24 crates (6 racks) are available, as shown in fig. 4. For the TGC detector, 34 crates (8.5 racks) are available. This means that at least 5 HV distributors should be accommodated in each crate.
The above-described topology must be implemented in the HV prototype, so that it will be possible to test a real part of the system.

1.1 *Summary of the HV generation and distribution features*

The HV generation module (HVG) must:

- Supply the HV to the distribution boards according to the following specifications;
- Supply the LV to the distribution boards for their functioning;
- Provide the parameter settings for the control of the HV generation and for the functioning of the distribution boards, included their LV power supplies;
- Manage the setting and monitoring parameters of the HV primary channels and the HV secondary channels. The HV primary channel is referred to the single channel of the HV generator, whereas the HV secondary channel is referred to the single channel of the HV distributor.

The HV distribution board (HVD) must:

- Split the single HV primary channel in 6 (or 8, in case of different modularity) HV secondary channels;
- Set and monitor, through the on-board controllers, the voltage, current and channel-related parameters for each HV secondary channel;
- Communicate to the linked HV generator all the information necessary for its own functionality and for the settings and monitoring of the HV secondary channels.

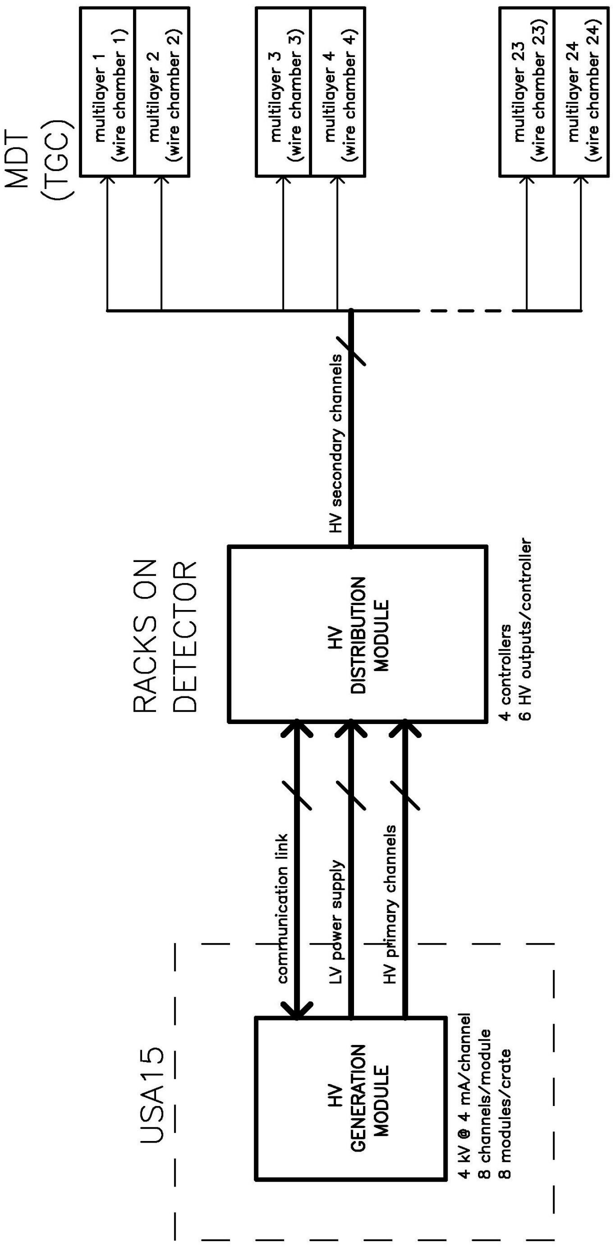

Fig. 2 – Block diagram of the HV system

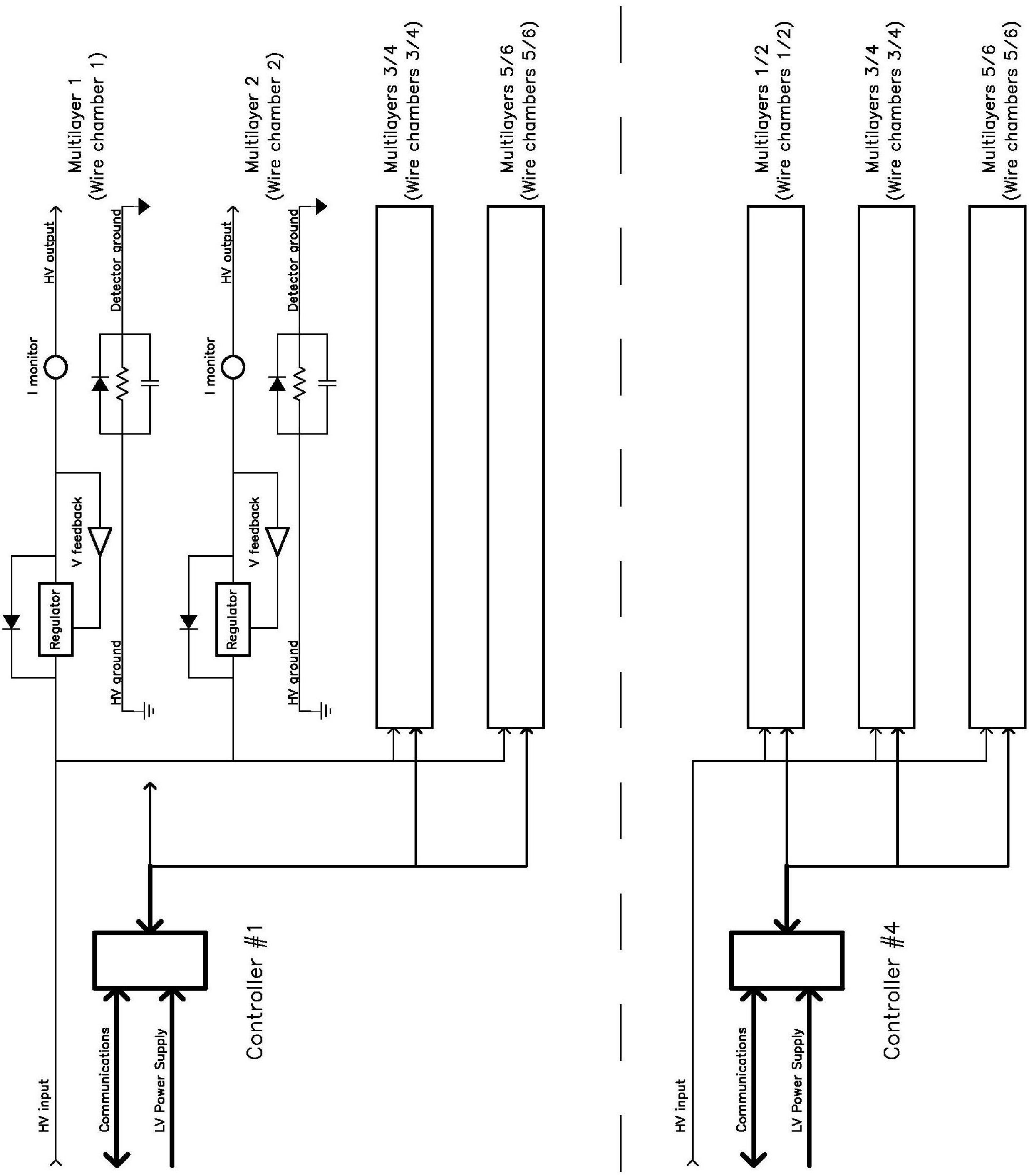

Fig. 3 – Block diagram of the HV distribution

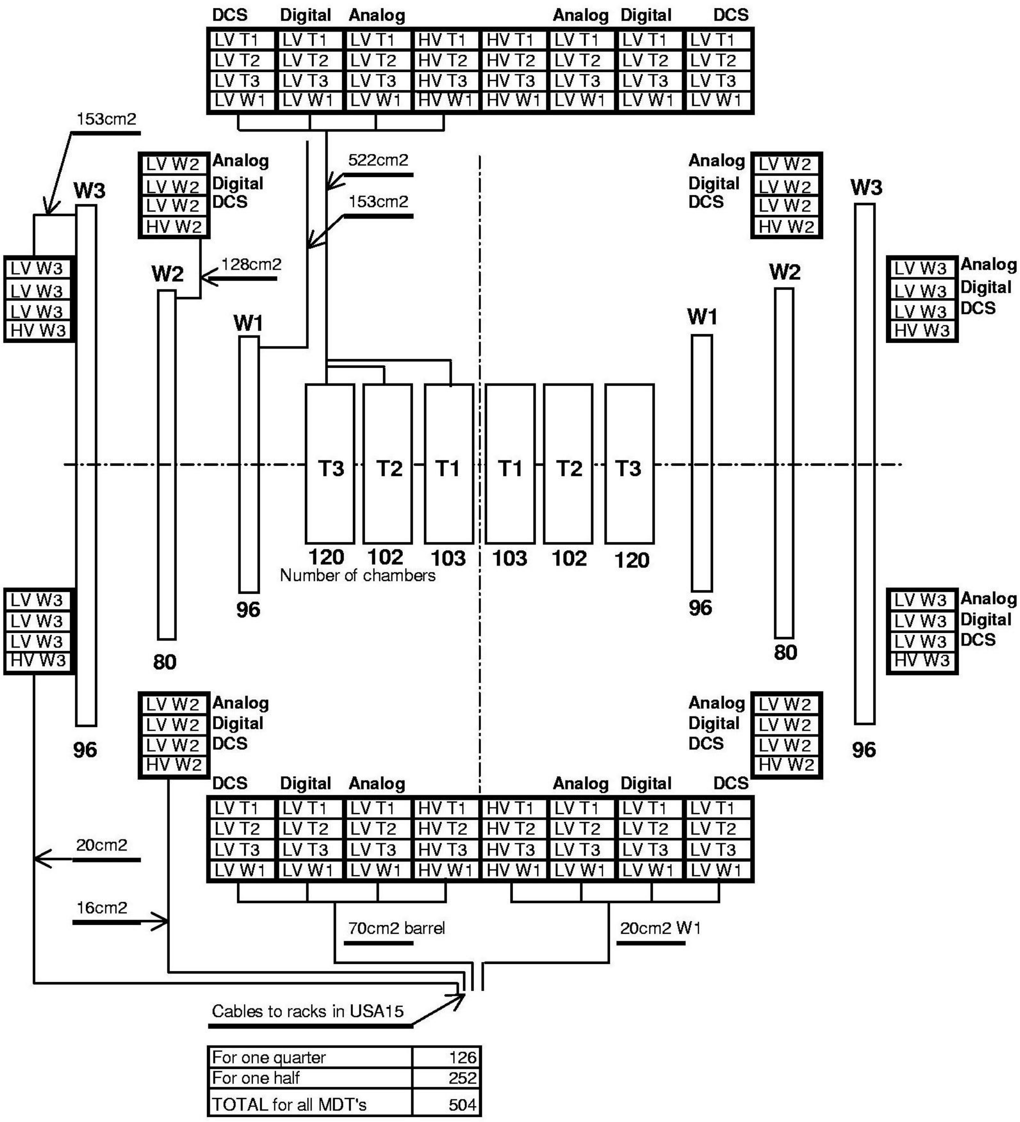

Fig. 4 – Detailed description of the racks for the MDT detector (4 crates/rack)

2. HV generation module

2.1 Mechanical requirements

The prototype of the HV generator must be a module compatible with an industrial multichannel HV modular system, easily available on the actual market, so that the system central CPU and power supplies carry out all the control, interface, monitoring and LV power supply functions.

Moreover, a modular system allows a better optimization of the available resources and a faster replacement in case of failure.

The module must contain at least 8 HV primary channels. Its width must not be greater than 10 TE (50.8 mm), so that the minimum number of modules per crate be 8. Its height must not exceed 6 HE (266.7 mm, or 6 U), so that a minimum of 2 HE can be left for the fan unit.

For each HV primary channel an Enable jumper must be provided on the front panel, unless a multipin connector is used for the HV outputs. In this case, the Enable jumper must be one for all the HV primary channels, and it must be included in the connector.

For each HV primary channel there must be a HV status indicator on the front panel, typically a red LED, signaling that the channel is ON.

On the front panel, a hardware regulation of the maximum allowed output voltage for all the channels of the module must be foreseen. Typically, it is a trimmer.

The HVG module must be properly keyed in order to allow the live insertion/extraction, so that to avoid to turn off the power of a complete crate in case of a single channel failure.

2.1.1 Connectors

The 8 HV primary channels should use the standard SHV connectors. A HV multipin connector is allowed if it can be easily found on the market, its price is competitive with respect to the SHV solution (the pair male-female plus pins must be considered), and it satisfies the electrical requirements specified below.

The LV power supply for the HVD is presumably composed of 3 wires per channel (positive, negative and ground), plus 2 sense wires. The total number of LV connections per HVG should be 40. A multipin connector, for example D-sub, should be used for the LV power supply lines.

The communication lines between the HVG and the HVD should use a standard multipin signal connector, like IDC or D-sub.

Being the HV, LV and communication lines linked to the same physical place (a HVD), the use of one high density multipin connector for all the lines is not forbidden, assuming it fits the three requirements written above.

The mechanical requirements are summarized in Table 2.1.

Table 2.1 – hvg mechanical requirements

Number of channels/module	8 min
Number of modules/crate	8 min
Maximum module width	10 TE max
Maximum module height	6 U max
Hv on led	One/channel
Hard-wired hv enable	One/channel if shv is used, otherwise one/module
Hardware hv max	One/module, multiturn trimmer
Live extraction/insertion	Yes
Hv connector	Shv (multipin as alternative)
Lv connector	Multipin
Communication connector	Multipin

2.2 Electrical requirements

Each HV primary channel must supply a fixed DC voltage of 4 kV, with positive polarity. The sourcing maximum current must be 4 mA.

The allowed peak-to-peak noise (ripple) depends on the capacitance of the elementary detector cell (a drift tube for the MDT detector and a group of wires for the TGC detector), on the maximum allowed noise for the front-end discriminator and on the integration time of the front-end preamplifier. The capacitance of the longest drift tube can reach 60 pF, whereas the capacitance of one group of wires in a TGC wire chamber can exceed 200 pF, but the allowed noise for the drift tubes is more than one order of magnitude lower. As a consequence, the peak-to-peak noise must be less than 150 mV in the frequency band up to 10 kHz, and must be less than 15 mV in the frequency band from 10 kHz up to 100 kHz, which is the operating band of the switching power supplies.

The long-term stability, including temperature effects, is determined by the maximum allowed variation of the spatial resolution for the MDT drift tubes, and by the extension of the working plateau for the TGC wire chambers. Assuming the maximum variation of the spatial resolution to be 5 μm, and the ratio between the resolution variation and the HV variation to be 0.5 on average

(ATL-COM-MUON-2000-002), the long-term stability must be better than ±5 V. This value is also in agreement with the TGC data.

2.2.1 Connector leakage current

The leakage current of the HV connectors (SHV or multipin) must be below the resolution of the HV secondary channel current, 200 nA, at full scale voltage, 4 kV.

2.2.2 Grounding

For safety reasons, the ground of the HV primary channels must be connected to the earth.
The LV fed to the HVD must be floating, with sense lines in order to compensate for the voltage drop along the wires.
The communication signals must be optically decoupled, in order not to decrease the noise margin of the HVG and HVD receivers. The insulation voltage should be at least 100V.

2.2.3 Power consumption

For each module, the total power consumption, HV and LV, must be lower than 250 W. For the single HV primary channel, it must be lower than 30 W at the maximum current, 4 mA, taking in account the LV supplied to the HVD.
The electrical requirements are summarized in Table 2.2.

TABLE 2.2 – HVG ELECTRICAL REQUIREMENTS

OUTPUT VOLTAGE/CHANNEL	DC 4 kV FIXED
OUTPUT CURRENT/CHANNEL	DC 4 mA MAX
PEAK-TO-PEAK OUTPUT NOISE/CHANNEL	150 mV MAX, 0 TO 10 kHz 15 mV MAX, 10 TO 100 kHz
LONG-TERM STABILITY/CHANNEL	±5 V MAX
HV MULTIPIN CONNECTOR LEAKAGE CURRENT	200 nA @ 4 kV MAX
HV GROUND	CONNECTED TO THE EARTH
LV GROUND	FLOATING
COMMUNICATION LINES DECOUPLE	OPTICAL, 100V V_{BD} MIN
POWER CONSUMPTION/MODULE	250 W @ 32 mA MAX

Power consumption/channel with The LV supplied to the HVD	30 W @ 4 mA max

2.3 Environmental conditions

The electronics cavern USA15 will be a relatively well-controlled environment. The HVG must satisfy the electrical requirements within a standard temperature range, 0 to 40 °C, and relative humidity range, 10 to 80 %RH.

The magnetic field is lower than 10^{-3} T.

The radiation background is negligible, near to the natural one.

Table 2.3 summarizes the environmental conditions.

Table 2.3 – HVG environmental conditions

Working temperature range	0 to 40 °C
Working humidity range	10 to 80 %RH
Magnetic field	10^{-3} T max
Radiation background	None

3. HV distribution module

3.1 Mechanical requirements

The HV distributor prototype must be a module compatible with industrial standard 19" crates. The LV is supplied by the HVG and there are no communications between the HVDs, so the crate should be a pure mechanical structure without power supply unit and backplane.

No fan tray must be used due to magnetic field. The maximum height of the module must be 6 HE (6 U). The maximum width depends obviously on the type of connectors used for the HV outputs. Anyway, it cannot exceed 16 TE (81.3 mm), in order to allow the insertion of at least 5 modules in a crate.

For each secondary HV channel there must be an ON status indicator, a LED, on the front panel.

3.1.1 Connectors

Three types of cables link the HVD to the HVG. The HV cables are 4 and are connected to the HVD via SHV connectors. The LV power supply cables should be 20, of which 8 used for sensing, and are linked through the same multipin connector mounted on the HVG for the LV. The communication lines use the same multipin connector mounted on the HVG.

The 24 HV outputs should use a multipin connector, supposed it follows the requirements already specified for the HVG. Otherwise, they must use SHV connectors.

Table 3.1 summarizes the mechanical requirements.

Table 3.1 – HVD mechanical requirements

Number of channels/module	24 min
Maximum module width	16 TE max
Maximum module height	6 U max
Hv on LED	One/channel
Hv input connector	Shv
Lv connector	Multipin
Communication connector	Multipin
HV output connector	Multipin (shv as alternative)

3.2 Electrical requirements

Each HVD is divided into 4 independent sections. Each section receives one HV primary channel, and splits it in 6 HV secondary channels. Each section is managed by a controller microchip, whose functions are the control of the HVD and the communication exchange with the linked HVG.

A linear regulator, as shown in fig. 4, drives the HV output. It allows the output voltage to be set and monitored between 0 and 4 kV.

A limiting circuit must control the output current. The maximum allowed current should be 1 mA. This limit, summed over the 6 channels, is greater than the maximum current generated by the HVG, but this overcurrent permits an increase of the leakage current due to sparks in some tubes/wires without tripping the channel.

The output voltage must be set with steps of 1V.

The output current limit must be hardware implemented and software programmable between 0 and 1 mA with a resolution of 200 nA.

The output voltage accuracy (the difference between the set value and the monitored value) for each channel at 25 °C, and the repeatability at constant load and temperature, must be lower than ± 1 V at full scale.

The long-term stability must be equal to the value required for the HVG, as well as the peak-to-peak noise.

The voltage and current monitoring resolutions must be respectively of 1 V and 200 nA.

The controls should allow a ramp-up and ramp-down feature, settable between 10 V/s and 500 V/s with 1 V/s steps. The current trip limit must be programmable from 1 μs up to 100 μs with 1 μs steps and a maximum detect time of 100 ms.

3.2.1 Connector leakage current

The leakage current of the input and output HV connectors (SHV or multipin) must be below 200 nA at full scale voltage, 4 kV.

3.2.2 Grounding

For each HV secondary channel, the detector ground must decouple the HV ground. A resistive-capacitive circuit, as shown in fig. 4, can be used for this purpose. Its final values will be determined experimentally after the detector installation. Anyway, the resistance value should not exceed 1 kΩ, in order to avoid an excessive voltage drop (other 1 kΩ resistors are placed in series to the HV hot line and to the HV ground on the hedgehog boards for the MDT detector).

Since a negative HV with high current could be used for curing, a HV high current diode ($I_F >$ 200 mA) is placed in parallel to the resistor, in order to limit its power consumption.

The LV power supply ground must be connected to the HV ground via a high impedance path, using the resistive-capacitive circuit above described, or diodes, or a saturable insulation inductor.

The communication lines must be optically decoupled, as in the HVG. The minimum insulation voltage should be at least 100 V.

3.2.3 Power consumption

In order not to exceed the power consumption limits imposed to the HVG, each section of the HVD must not dissipate more than 10 W (LV and HV), which means 40 W per module.

The electrical requirements are summarized in Table 3.2.

TABLE 3.2 – HVD ELECTRICAL REQUIREMENTS

Number of sections/module	4
Number of controllers/section	1
Number of hv secondary channels/section	6
Hardware current limit	1 mA min
Output voltage range	0 – 4 kV
Output voltage set resolution	1 V
Software Output current set range	0 – 1 mA
Output current set resolution	200 nA
Output voltage monitor resolution	1 V
Output current monitor resolution	200 nA
Output voltage accuracy at 25 °C	± 1V max
Output voltage repeatability at constant Load and temperature	± 1V max
Output voltage long-term stability	± 5V max
Peak-to-peak output noise/channel	150 mV max, 0 to 10 kHz 15 mV max, 10 to 100 kHz
Ramp-up and ramp-down range	10 to 500 V/s
Ramp-up and ramp-down resolution	1 V/s
Current trip range	1 to 100 µs
Current trip resolution	1 µs
Current trip detect time	100 ms max
HV Multipin connector leakage current	200 nA @ 4 kV max
Hv ground decouple to detector ground	Resistive-capacitive circuit with parallel hv diode
Lv ground decouple to hv ground	Resistive-capacitive circuit
Communication lines decouple	Optical, 100 V V_{BD} min

Power consumption/section	10 W max
Power consumption/module	40 W max

3.3 Environmental conditions

The UX cavern will be a controlled environment, but due to the huge expected installed power, 200 kW, the temperature could vary from 17 °C at the floor level up to 24 °C at the ceiling level. Then, the working conditions for the HVD should be the same already requested for the HVG, 0 to 40 °C and 10 to 80 %RH.

The calculations of the fringe magnetic field in the positions where the racks will be placed show that it could be very high, up to 1 T, although on average it should be 0.1 T.

The radiation background, integrated over 10 years and with a safety factor of 5, is estimated to be 10 Gy (1 kRad) photon dose and 10^{12} neutrons/cm^2.

The environmental conditions are shown in Table 3.3.

Table 3.3 – HVD environmental conditions

Working temperature range	0 to 40 °C
Working humidity range	10 to 80 %RH
Magnetic field	1 T max
Radiation background over 10 years	1 kRad photons 10^{12}/cm^2 neutrons

4. System parameters

The HVG must exchange communications with the external world. The implemented protocol should be a simple RS-232C serial line, to which an alphanumeric terminal can connect, or a more complex Ethernet line, which offers the possibility of remotely controlling the system. Other interfaces, like a keypad, or other protocols, like CANbus or Profibus, could be implemented, but the serial line or the Ethernet line, one of the two, is mandatory.

The HVG firmware must manage the set and monitoring of all the HV secondary channels of the HVD, as well as the parameters of the HV primary channels.

The settable parameters of the HV primary channels should be:

- SYSTEM LOGIN AND PASSWORD. Needed to avoid unauthorized accesses (optional for the prototype)
- POWER ON/OFF. Each HV primary channel must be switched on and off.
- VMAX hardware. It must be visualized on the channel parameter page.

The settable parameters of the HV secondary channels should be:

- CHANNEL NUMBER AND NAME. An absolute number and a relative, editable name must characterize each channel.
- VSET. Each channel must be set to the proper operating voltage.
- ISET. Each channel must have a proper current limit.
- VMON. Each channel is monitored, and the output voltage is displayed on the channel parameter page. If the value is equal to the previous reading, or if it is inside a predetermined window, the system CPU can avoid displaying it, in order to save time.
- IMON. For each channel, the output current is monitored and displayed on the channel parameter page. If the value is equal to the previous reading, or if it is inside a predetermined window, the system CPU can avoid displaying it, in order to save time.
- POWER ON/OFF. Each HV secondary channel must be switched on and off.
- VMAX software. The output voltage of each channel must be limited to the maximum value established by this parameter. It could be unique for each HVD section.
- RAMP-UP. Each channel must increase its output voltage following the rate established by this parameter. It could be unique for each HVD section.
- RAMP-DOWN. Each channel must decrease its output voltage following the rate established by this parameter. It could be unique for each HVD section.
- TRIP. It represents the time within which the channel behaves like a current generator. After this time, the power down is initiated, at a rate established by the ramp-down parameter. It could be unique for each HVD section.

The commercial system in which the HVG is inserted should be equipped with the standard system status and controls, like KILL, INTERLOCK and ENABLE.

Each of the described parameter must be programmable at the channel level, where not differently specified.

There should be the possibility of grouping different channels, so that their parameters can be programmed by group commands instead of channel commands.

The HVG firmware must allow setting and testing the available communication interfaces.

The system parameters are summarized in Table 4.1.

Table 4.1 – system parameter requirements

Communication protocols	Rs-232c or Ethernet mandatory
Primary channel parameters	System login & password
	Power on/off
	Vmax hardware display
Secondary channel parameters Single channel and group programmable	Channel number and name
	Vset
	Iset
	Vmon
	Imon
	Power on/off
	Vmax software
	Ramp-up
	Ramp-down
	trip