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Cabling Scheme for the Hadronic Endcap Calorimeter

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1 Introduction

The signal, low voltage (LV), high voltage (HV) and calibration lines set different demands in terms of timing, safety, feedthrough connections and requested accessibility. In particular we forsee to be able to do the relevant module check-out using these service lines in the module construction phase (transport frame mounted), after the wheel assembly (horizontal position) and after turning the wheel into the vertical position (i.e. before inserting into the cryostat). These operations define the boundary conditions for the mechanical construction.

2 Signal Lines

The Fig. 1 shows the general lateral and longitudinal segmentation of a module. Notches for signal, calibration and HV lines are indicated (on the side of the module) as well.
Based on the feedthrough allocation, the signal lines are symmetric with respect to individual quadrants. The demand for equal channel timing sets tight limitations on the cable length variation for the signal output cables (from the motherboard to feedthrough). To have a minimal timing spread between the signals from individual electrodes which are being summed to one read-out channel, the cabling has to follow as closely as possible the real particle shower propagation.
The Fig. 2 shows the strip line connector (50 Ω impedance) which guides the individual electrode signals refering to one read-out sub-segment to the motherboard. The back plane serves as ground bus. All conducting surfaces are gold plated. This connector runs perpendicular to the 25mm (or 50mm) copper plate orientation in notches of 39 mm width and 3 mm depth. Two read-out electrodes are added locally to one line. The connector serves two radially adjacent read-out sub-segments in parallel and runs over 8 copper plates. Small tabs (with soldered pins) from the signal electrodes are passed through holes in the strip line connector to special sockets. Close to the end of the connector the transition from the strip line to the 50 Ω impedance coax cable is done via a soldered joint. These cables leave parallel to the copper plate orientation in special notches and run directly to the related motherboard at the outer ($R = 2.03\ m$) cylindrical surface of the module. For longitudinal read-out segments 2 and 3, where 16 rather than 8 read-out electrodes are summed, a second strip line connector is added. For these read-out segments two strip line connectors are used. The corresponding calibration lines are connected via a jumper cable, which is soldered to the strip line connector. The calibration input cables are fed in close to the beginning of the strip line connector via notches parallel to the copper plate, thus simulating the evolution with time of a real particle response as close as possible.
The cabling of the module will be done immediately after the stacking of the module. There is free access to the side of the module, where the strip line connectors are placed. The connectors including the optional ganging of two connectors as well as the soldered connection to the signal and calibration cables are done prior to mounting the strip line connectors, using for all positions the appropriate cable lengths.
The signal output cables are connected via connectors at the mother boards (each connector uses up to 8 lines,there are 7 connectors for the front module and 4 connectors for the rear module). These output cables are routed on top of each other to the back plane of the module, regrouped within the quadrant and routed in cables of 64 lines to the feedthrough, with the boundary condition of equal length. The cabling is done symmetrically for each quadrant. Therefore for each module at the back plane some space is reserved to store the extra cable length. Because this space is only required after turning the wheel into the vertical position,

and so we forsee to use the centre region of the back plane, which normally is blocked prior to this operation by the transportation frame. The Fig. 3 shows schematically the space allocation at the back plane of a module. The actual size has to be defined following the detailed layout of the cabling scheme for one quadrant.

3 Calibration Lines

In order to have the calibration signal match the real signal as closely as possible, the calibration pulse is fed in at the level of the electrode. Therefore, additional calibration lines deliver the calibration signal to all electrodes served by the signal strip line connector. Given the requirement of 50 Ω impedance over the full length of the distributionline, one calibration line can serve at most 32 read-out electrodes in reality.
An important constraint for the distribution of the calibration lines is the dynamic range required at the level of an individual preamplifier and at the level of the summing. For the first and last longitudinal segments the dynamic range at both levels is identical, i.e. the maximum signal at the summing stage corresponds to the sum of the maximum of the preamplifiers being summed in this particular read-out tower. Consequently one calibration line is in this case sufficient to pulse all read-out electrodes of this read-out tower in parallel. Therefore the signal connector in the rear wheel has one common calibration line, pulsing two radially adjacent read-out electrodes with 16 pads each. Calibrating two neighbouring read-out electrodes in parallel precludes the measurement of the related cross talk. However this measurement has been done in module -1, yielding typical values for this cross talk at the level of 1%. Since this level is so small the chosen technique seems to be adequate.
In the second longitudinal read-out segment there is a difference of a factor of two between the dynamic range required at the preamplifier level and at the summing stage. Therefore two calibration lines are required for a given read-out tower, one pulsing the first eight read-out electrodes and one the second eight read-out electrodes. Therefore a different calibration scheme has been adopted for the front wheel (HEC 1). Each signal connector, which covers 8 read-out electrodes, has two calibration lines. In the first longitudinal read-out segment this line feeds all eight read-out electrodes, the dynamic range requirements being here identical to the last longitudinal read-out segment. The second longitudinal read-out segment is covered by two signal connectors, each one extending over eight read-out electrodes. The calibration signal is ganged from the signal connector of the first longitudinal read-out segment to the first signal connector of the second longitudinal read-out segment via jumpers. Before passing on to the second signal connector of the second longitudinal read-out segment the two calibration lines are swapped.
The cabling for the calibration lines is symmetric for one quadrant. We forsee the calibration cables running from the feedthrough to a small calibration distribution board at the back plane of each module. The space reserved for this board is about 15×4 cm . The cabling is done only after turning the wheel into the vertical position. The cable lengths must again be equal, and so a dedicated region at the back plane of the module will be used to store extra cable.
The calibration input cables are routed from the board on the back plane, to the outer radius of the wheel, then under the motherboards, and finally along slots in the copper plates to the front of the strip line connector in the first and third read-out segment. The space reserved at both sides of the motherboard accomodates up to 28 cables. The calibration cables are then soldered to a trace that runs down the connector. A set of 5 $k\Omega$ resistors connects the calibration line to the signal line (see Fig. 2), providing the means to input the calibration

signal directly to the signal lines.
The calibration cables from the strip line connector will be soldered to the distribution board immediately after the stacking of the module. In order to mount this board in the horizontal position (with the transport frame mounted), the board has to be close to the inter-module gap and the free space above ground in the stacking position must be sufficient for connector access. The input connector at the level of this board for the calibration lines is as close as possible to the inter-module gap, allowing easy connection in all test situations: after stacking or transportation, following the wheel assembly in the horizontal position on the wheel assembly table, after rotating the wheel, and during and after insertion into the cryostat.
In this layout each calibration line (i.e. calibration generator) feeds 24 electrodes in the front module and 32 electrodes in the rear module. Therefore 28 calibration lines are required for the front module and 14 calibration lines for the rear module.
The Table 1 shows schematically the calibration scheme, the tables 2 - 8 the details of the assignment of individual calibration lines to the pads of the various read-out board families.

4 High Voltage Cables

The connection of the HV and ground to the read-out board (ROB) and EST is done following the strip line connector technique, again done on the side of the module. For each readout section we forsee to supply 4 independent HV lines, feeding the EST 1, EST 2, ROB 1 and ROB 2 HV potentials. Two ground connections (EST 1 and EST 2) are required in addition. For safety and to limit any current due to pile-up, two HV connections are foreseen for each plane: one close to the inner radius and one at the outer ($R = 2.03\ m$) cylinder surface of a module. The HV connection to the strip line connector is done via tabs similar to the signal connection (see Fig. 4). The tabs are isolated (kapton) on the side facing the module. The non-isolated plane of the tab is covered - as in the case of the signal lines - with a kapton sheet placed in the inter module gap prior to the wheel assembly. Therefore we can connect with each strip line connector two HV lines and one ground line. For the connection of the remaining three lines the identical strip line connector is rotated by 180 degrees. The ground tabs run in the center and terminate at screws mounted to the copper plates. Two HV buses run on each side and serve for the parallel connection of related planes of 8 LAr gaps. Given the width of the tabs (6 mm) and the guard zone between different HV/ground lines (2 mm), we estimate the width of a 3-connections strip line connector to be 35 mm. The related notch width for two connectors is therefore required to be 70 mm at minimum.
All HV lines (4 per section of 8 copper plates) are guided to a HV distribution board at the back plane of a module. Up to 8 lines have to pass in the same notch in addition to the two strip line connectors. Therefore the total width of the notch has to be about 73 mm.
As in the case of the signal strip line connector, the HV cables are soldered to the strip line connector prior to mounting the connector at the module. After module assembly these lines are connected (pins and socketts) to the HV distribution board, which is mounted at the back plane. In order to provide the required HV ganging scheme, the lines in the notch of the front(rear) module, will be connected to 8(4) independent HV lines so as to provide four independent lines to each read-out depth. Again, in the stacking position, i.e. in the horizontal position, this board has to be mounted on the module. Therefore it has to be again close to the side of the module. The input HV lines (from the feedthrough) are connected via a connector at this board. Because of accessibility this connector has to be as close as possible to the inter

module gap. Because each HV line splits into 2 lines, space has to be foreseen for guiding up to 12 HV lines from the low-r to the high-r region at the back plane of the module. The size of the HV distribution board is 13.3 × 9.6 cm.
The final connection from this HV distribution board to the relevant feedthrough (one for the whole wheel) is of varying length, depending on the module position within the wheel, and has to be added after insertion of the wheel into the cryostat.

5 Low Voltage Lines

The low voltage lines (4 per motherboard) are connected via connectors at the motherboard. They are routed to the back plane of the module, passing again on either side of the motherboard. At the back plane they are soldered to a low voltage distribution board. The low voltage lines coming from the feedthrough are connected via connectors to this board. Again, this board has to be mounted after stacking in the horizontal position. Therefore it has to be positioned as close as possible to the inter module gap. Connecting up to 12 input and output lines, we forsee a space of about 7 × 7 cm.
The variation of the length of the low voltage lines is not a critical issue. On the other hand we would like to maintain a standard voltage drop across the cable for all low voltage lines. Therefore we would like to have them in a standard length. The low voltage cabling being symmetric for each quadrant has thus to allow for extra cable length at the backplane of each module. These cables will be again connected only after turning the wheel into the vertical position. Therefore some space occupied prior by the module/wheel support structure can be used in this case.

6 Summary

A summary of the number of channels, cables and connectors in the feedthroughs are given in Table 9.

Read out segment	1	2	2	3	3
LAr cells	1-8	9-16	17-24	25-32	33- 40
η bin					
1	○	○	□	△	△
2	□	□	○	△	△
3	•	•	⋆	◇	◇
4	⋆	⋆	•	◇	◇

Table 1: Symbolic calibration scheme for the three longitudinal segments with 8,16,16 gaps. Each symbol represents a given calibration generator. Shown is the scheme for 4 neighbouring η towers, separately for each section of 8 gaps which are ganged with a single connector. Each connector serves two neighbouring η towers and has one or two calibration lines respectively.

η bin (left)	η bin (right)	generator (left)	generator (right)
1a	2a	1	2
1b	2b	3	4
3a	4a	5	6
3b	4b	7	8
5	6	9	10
7	8	11	12
9	10	13	14
11	12	15	16
13	14	17	18
15	16	19	20
17	18	21	22
19	20	23	24
21		25	
22		27	
	23		26
	24		28

Table 2: Generator number for different η towers of the first longitudinal segment for cell 1-8

η bin (left)	η bin (right)	generator (left)	generator (right)
1	2	1	2
3a	4a	3	4
3b	4b	5	6
5a	6a	7	8
5b	6b	9	10
7	8	11	12
9	10	13	14
11	12	15	16
13	14	17	18
15	16	19	20
17	18	21	22
19	20	23	24
21		25	
22		27	
	23		26

Table 3: Generator number for different η towers of the second longitudinal segment for cell 9-16

η bin (left)	η bin (right)	generator (left)	generator (right)
3a	4a	1	2
3b	4b	7	8
5a	6a	5	6
5b	6b	11	12
7	8	9	10
9	10	15	16
11	12	13	14
13	14	19	20
15	16	17	18
17	18	23	24
19	20	21	22
21		27	
22		25	
	23		28

Table 4: Generator number for different η towers of the second longitudinal segment for cell 17-24

η bin (left)	η bin (right)	generator (left)	generator (right)
3	4	29	30
5a	6a	31	32
5b	6b	31	32
7a	8a	33	34
7b	8b	33	34
9	10	35	36
11	12	35	36
13	14	37	38
15	16	37	38
17	18	39	40
19	20	39	40
21		41	
22		41	
	23		42

Table 5: Generator number for different η towers of the third longitudinal segment for cell 25-28

η bin (left)	η bin (right)	generator (left)	generator (right)
5a	6a	31	32
5b	6b	31	32
7a	8a	33	34
7b	8b	33	34
9	10	35	36
11	12	35	36
13	14	37	38
15	16	37	38
17	18	39	40
19	20	39	40
21		41	
22		41	
	23		42

Table 6: Generator number for different η towers of the third longitudinal segment for cell 29-32

η bin (left)	η bin (right)	generator (left)	generator (right)
5	6	31	32
7a	8a	33	34
7b	8b	33	34
9	10	35	36
11	12	35	36
13	14	37	38
15	16	37	38
17	18	39	40
19	20	39	40
21		41	
22		41	
	23		42
	24		42

Table 7: Generator number for different η towers of the third longitudinal segment for cell 33-36

η bin (left)	η bin (right)	generator (left)	generator (right)
7a	8a	33	34
7b	8b	33	34
9	10	35	36
11	12	35	36
13	14	37	38
15	16	37	38
17	18	39	40
19	20	39	40
21		41	
22		41	
	23		42
	24		42

Table 8: Generator number for different η towers of the third longitudinal segment for cell 37-40

	Channels used	Channels free	Channels total	FT-connectors
Azimuthal wedge				
Signal cables	72	24	96	1.5
Calibration cables	42	6	48	0.75
Low voltage cables	20	4	24	0.375
Monitoring cables	16	0	16	0.25
Total	150	34	184	3
High voltage cables	20	0	20	
One quarter				
Signal cables	576	192	768	12
Calibration cables	336	48	384	6
Low voltage cables	160	32	192	3
Monitoring cables	128	0	128	2
Total	1200	272	1472	23
High voltage cables	160	0	160	
One Endcap				
Signal cables	2304	768	3072	48
Calibration cables	1344	192	1536	24
Low voltage cables	640	128	768	12
Monitoring cables	512	0	512	8
Total	4800	1088	5888	92
High voltage cables	640	0	640	
Two Endcaps				
Signal cables	4608	1536	6144	96
Calibration cables	2688	384	3072	48
Low voltage cables	1280	256	1536	24
Monitoring cables	1024	0	1024	16
Total	9600	2176	11776	184
High voltage cables	1280	0	1280	

Table 9: Number of channels, cables and connectors between modules and feedthroughs for the Hadronic Endcap Calorimeter

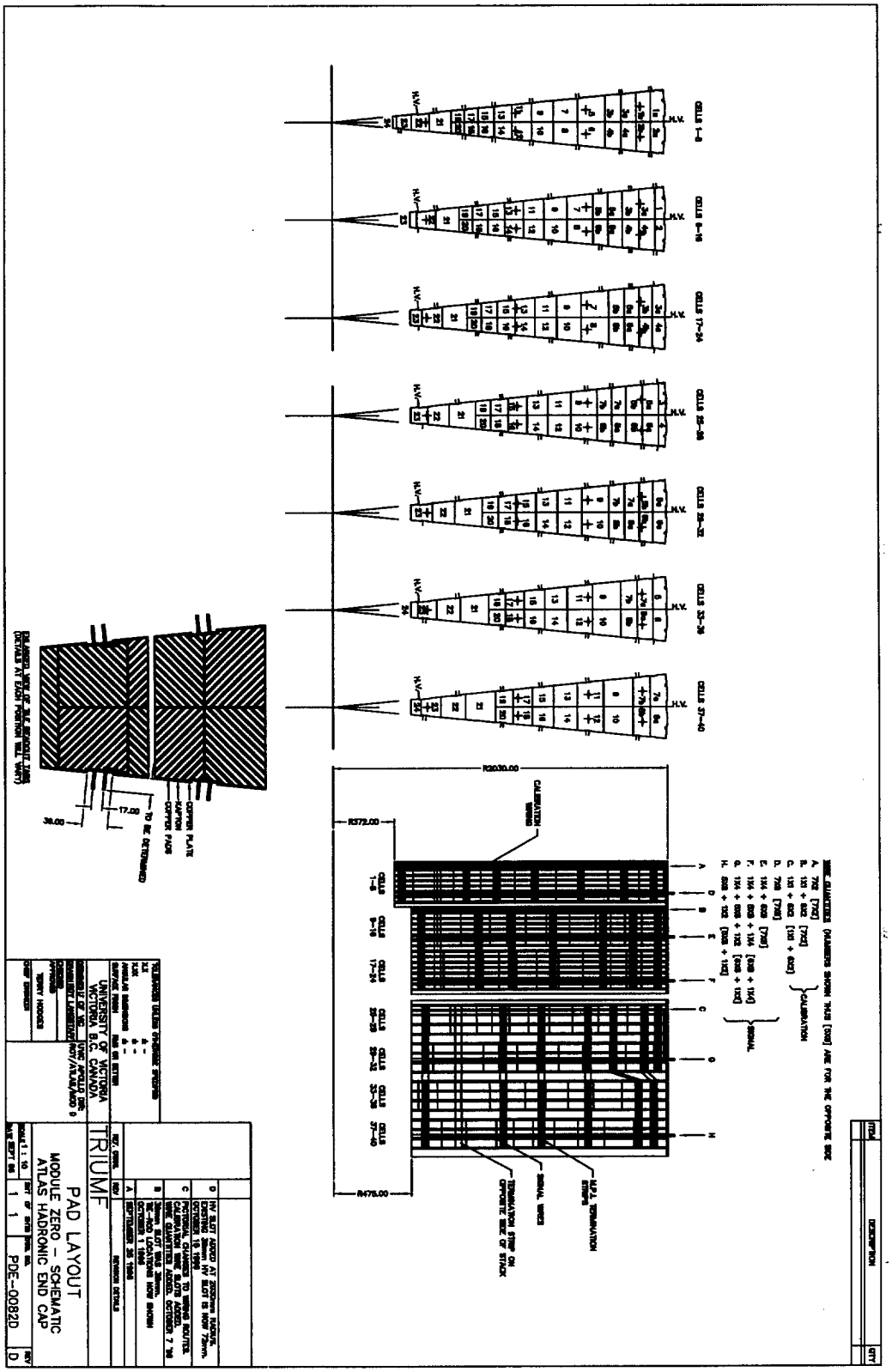

Figure 1: Lateral and longitudinal segmentation of the front and rear module.

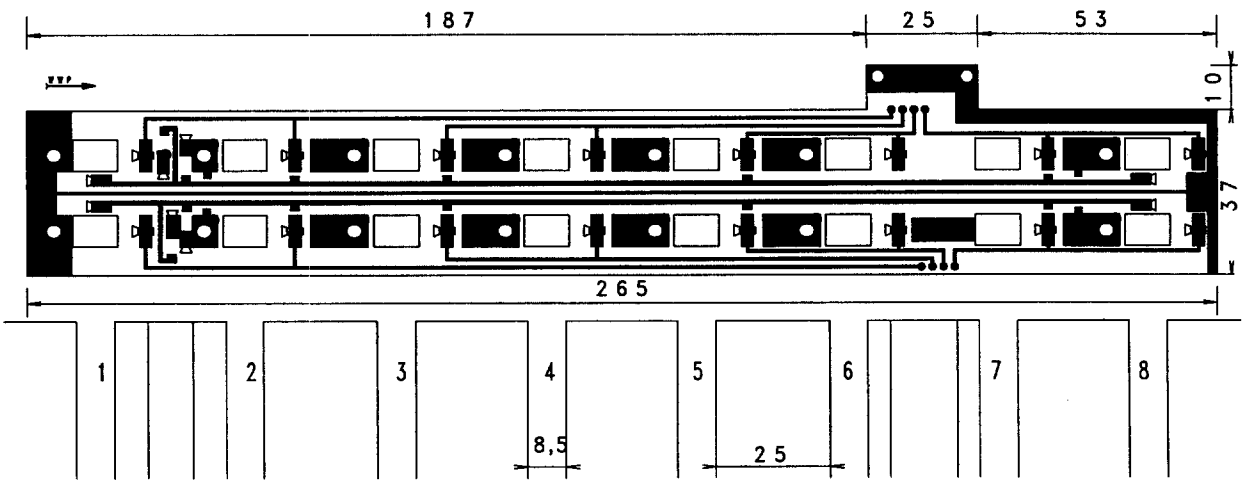

Figure 2: Layout of the signal strip line connector. The back plane serves as ground bus. All conducting surfaces are gold plated.

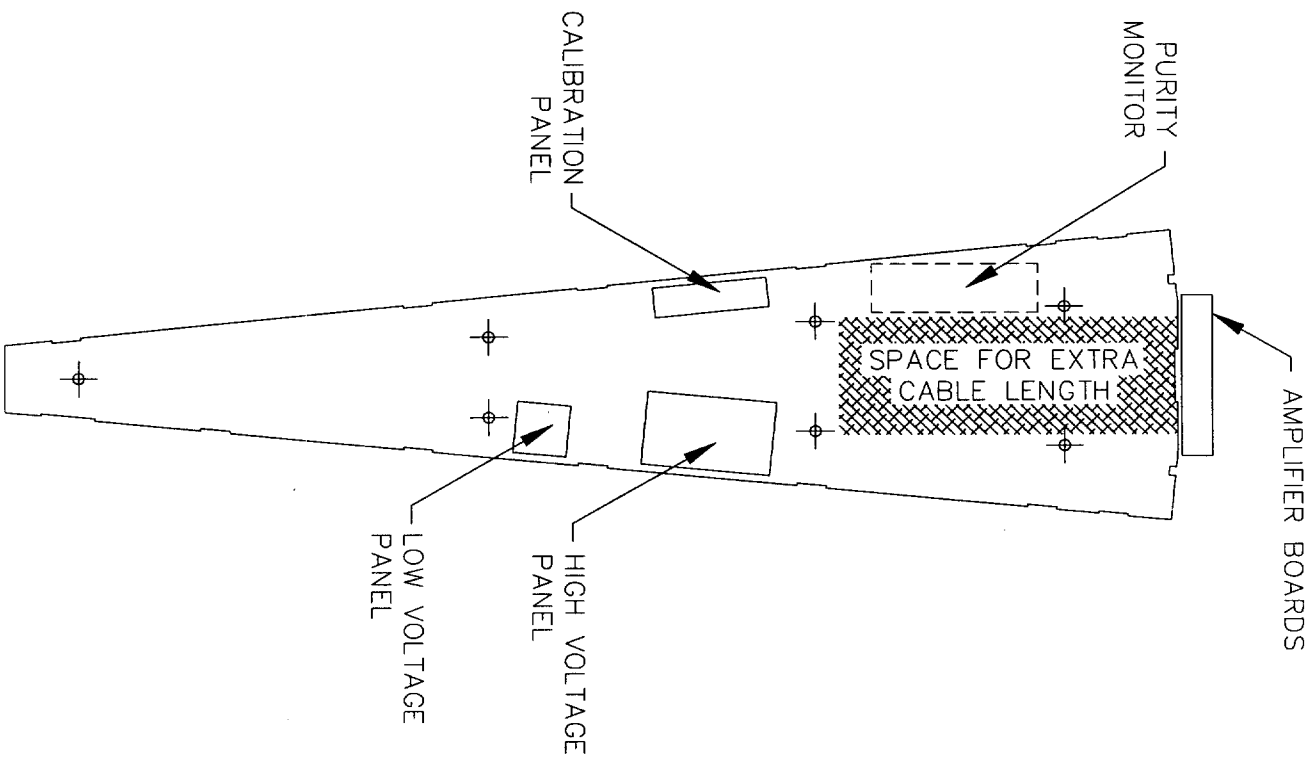

Figure 3: Schematic view of the back plane of a module. Shown is the space allocated for individual boards (calibration, high voltage and low voltage) and for additional extra cable length.

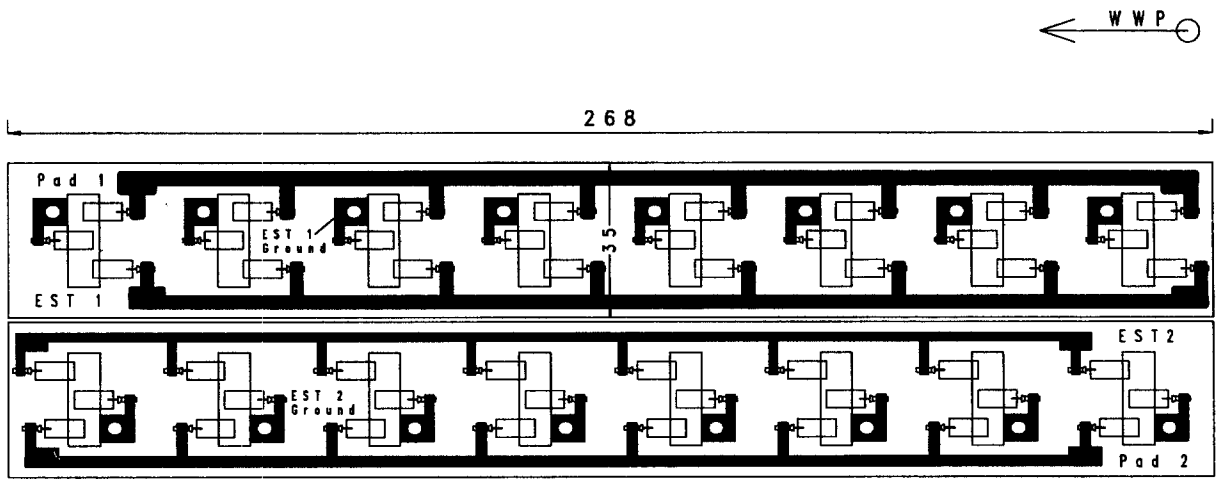

Figure 4: Layout of the HV strip line connector. Two connectors, with the second one rotated by 180 degrees, are used to serve for the four HV and two ground connections required per LAr gap.