

# HV-LV distribution in EUSO

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## Abstract

Some evaluations of the EUSO power supply system are provided, with special care for the pmts HV. The model for the voltage divider has identical tensions applied at each pair of dynodes. This report is an upgrade of the previous one and contains its established parts. An active HV voltage divider is studied and compared with the three tensions system. Systems of current limit protections are explored with some conjectures on the possible layout of the HV distributions at the micro- and macro-cells level.

## 1 HV Distribution

### 1.1 Introduction

The estimated background is calculated in [1], pag.29 that value will be used here.

Estimated background:  $10 p.e./\mu s$  per *pmt*.

Operating tensions of the *pmt*  $-900V$  Gain =  $10^6$ , *pmt* average current  $1.6\mu A$ .

The so called "analog" tensions (*pmt* HV, HV elevators, preamp. LV generators), grounds and cabling must be kept as separated as possible from any "digital" tension, cabling grounding and whatever can produce EMI on the "analog" sectors.

### 1.2 Single tension Setup

Current in the Voltage Divider (VD)  $16\mu A$  safety factor 10 i.e. ten times the average *pmt* current.

Power dissipation of the VD =  $900V * 16\mu A * 6000 pmt = 86.4W$  (115 W considering 0.75 the conversion efficiency of a CAEN DC/DC converter S 9030).

The full HV system in these assumptions can be formed by 24 CAEN S 9030 boards + at least other 24 redundant boards with a weight of Kg 5.92 (the weight of each board is Kg 0.12)

The estimated cost is 144000 Euro (cost 3000 EURO/board).

Each HV board works at half of its nominal power and serves 250 *pmt*. (or  $\sim 7$  macrocells with 36 *pmt* )

### 1.3 Three Tension Setup

The safety factor 10 of the current in the VD is probably too restrictive. With this current in the VD, the *pmt* working point is in a non-linear region. This could render complicate the calibration procedures of all the *pmt's*, and, due to the individual gain fluctuation of the *pmt*, an unsafe nearing to the interdiction region of some *pmt* cannot be excluded. For these reasons we will make this further study of the HV distributions with an additional factor of 5 in the current of the VD. So the current in the VD becomes 50 times the *pmt* background current. This is a factor 2 less than the optimal value suggested by some *pmt* producers.

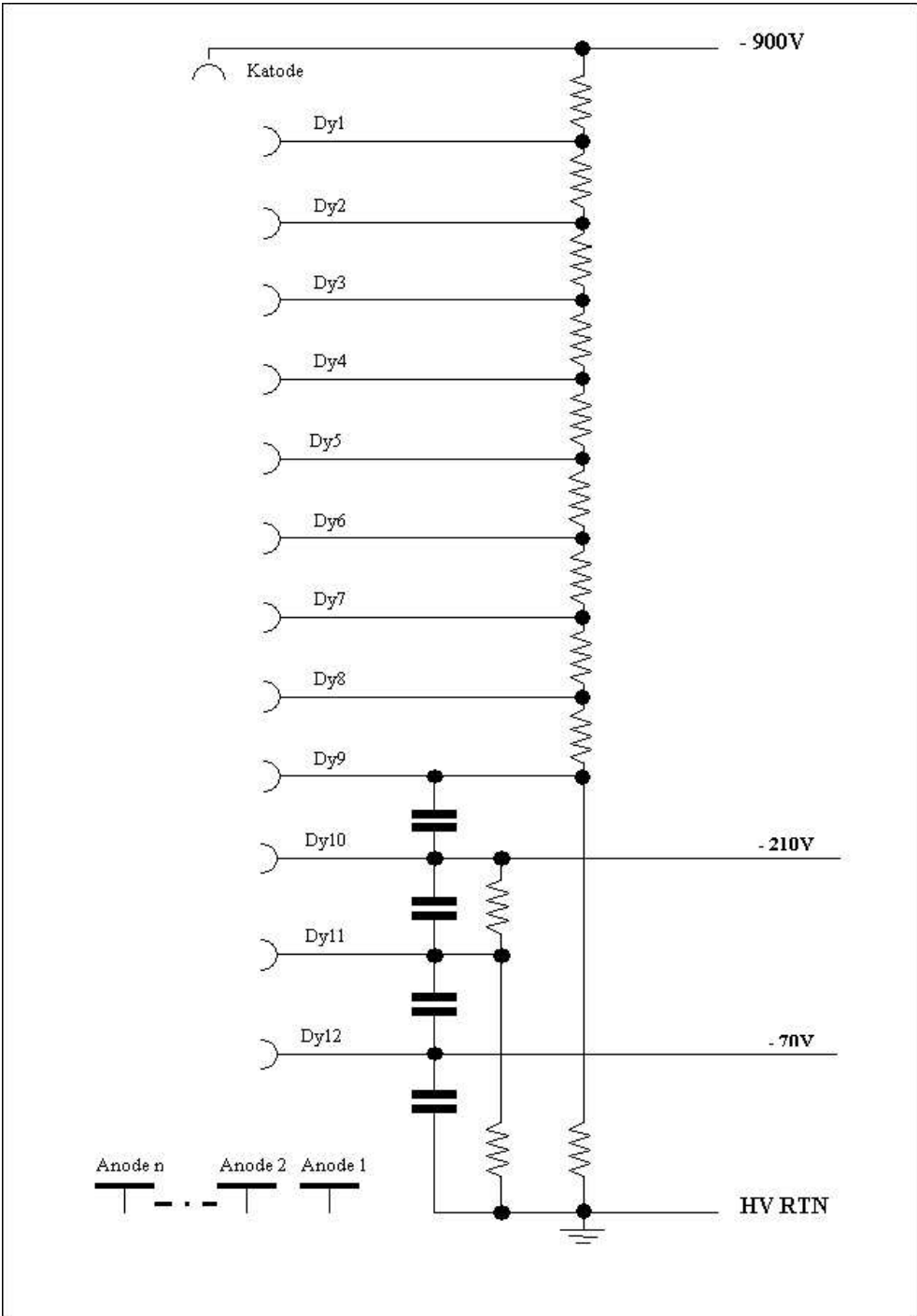


Figure 1: Setup of three tension distribution on a pmt voltage divider

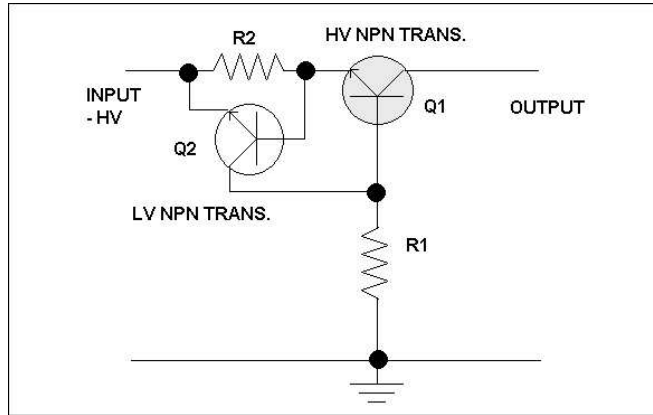


Figure 2: A scheme for the CLP

We use a constant tension distribution between each pair of electrodes (dynodes, cathode, anode) and a constant gain at each stage. This model requires very few assumptions about the true properties of the pmt, and it gives the maximum gain. Different tension distributions request a detailed information about the gain of each stages, it cannot be safely recovered from the data sheet of the pmt and must be obtained from the producer. In any case this model is the worst case for the power consumption.

Now the energy absorption of the VD is too high to be handled in the standard way (i.e. a single tension powering a series of resistors). We have to resort to an array of tensions to reduce the the energy dissipation of the VD. For the *pmt's*, the low duty factor of the detector cannot be invoked. A too long time (half hour) is requested by the *pmt* after an HV switch-off to reach a stable Gain. A standard suggested procedure to reduce the VD power absorption is the use of multiple tensions to power different sectors of VD. We will explore the set-up with three different tensions (Fig.1):

$$V_1 = -70V, V_2 = -210V, \text{ and } V_3 = -900V.$$

$V_1$  delivers the effective current circulating in the last dynode, ( $\sim 1\mu A$ ) contributing negligibly to the power budget. The other two tensions deliver respectively  $25\mu A$  and  $3.5\mu A$  per *pmt*. The power request is:

$$0.5W (V_1), 31.5W (V_2), 19.0W (V_3). \text{ For a total of } 51W \text{ and an effective absorption of } 68W.$$

The HV can be distributed by 6 CAEN S9030 DC/DC converter cards for each tension + 6 redundant cards (or more)for each tension. These numbers of HV elevators are based on the easier architecture of the HV distribution than to the power absorption. In fact, a single HV elevator is largely overdimensioned if dedicated to the -70 V production for the total detector.

With 18 "hot" cards S9030 (plus 18 "cold" cards) and an effective absorption of 68W the HV distribution can be realized with a much larger safety factor. Each group of three cards, delivering the three tensions: -70, -210, -900 serves 1000 pmt or  $\sim 28$  macrocells The total mass of the HV cards becomes kg 4.32 (estimated cost 108000 EURO)

## 1.4 HV Current Limit Protection (CLP)

The current limit protections (CLP) can be implemented as in Fig. 2. An HV-transistor ( $Q_1$ ) is kept in conduction by a base current given by the HV-generator and controlled by the resistor R1. The current protection is given by the  $Q_2$ -transistor: If the tension on R2 reaches the threshold tension of  $Q_2$ , it start to drive part of the  $Q_2$  base-current reducing its conduction. The outgoing current remains almost constant with value:

$$I_{lim} = I_{cc} = (0.65/R_2)\mu A \text{ (with } R_2 \text{ in } K\Omega).$$

If  $I_{nom}$  is the nominal output-current in normal condition and  $\beta$  is the minimum current gain of

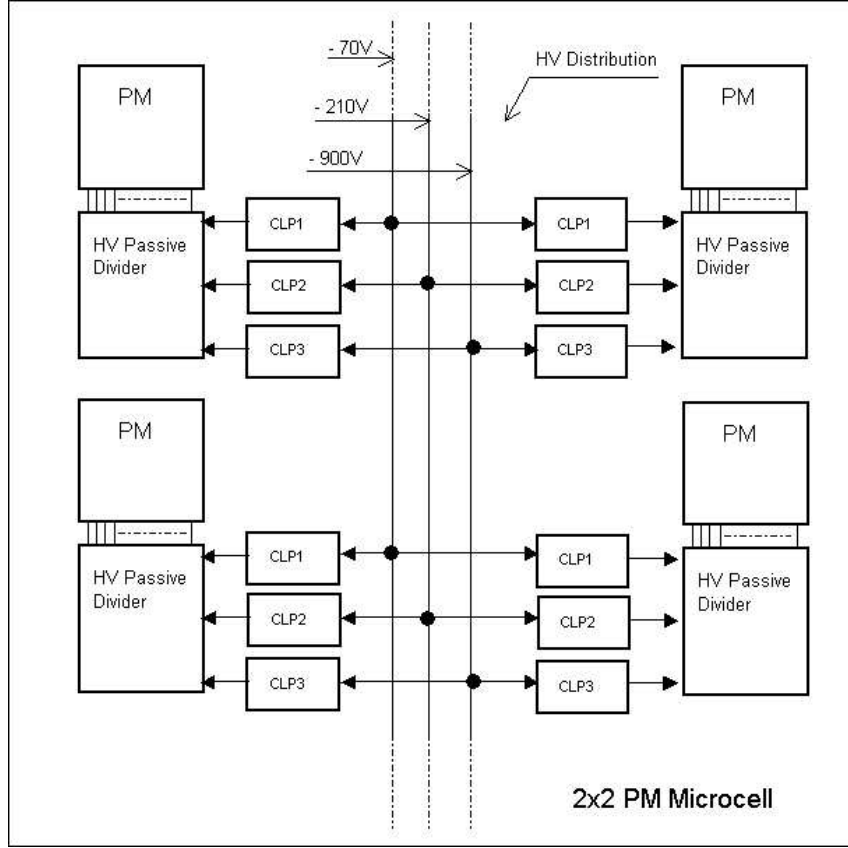


Figure 3: Distribution of the three HV tensions in a microcell, with a CLP for each tension and one VD for each pmt

$Q_1$  (with  $\beta \geq 10$ ), the data for the 210 V tension gives (CLP<sub>2</sub>):

$$I_{nom} = 25, V_{in} = 210 \text{ V}, \beta = 10, I_{lim} = I_{cc} = 40 \mu\text{A}$$

$$I_b = I_{nom}/\beta + 2 \mu\text{A} \text{ (} 2 \mu\text{A is the margin current)}$$

$$I_b = 25 \mu\text{A}/\beta + 2 \mu\text{A} = 4.5 \mu\text{A}$$

$$R_1 = 47 \text{M}\Omega$$

$$R_2 = 17 \text{K}\Omega$$

The protection efficiency (assuming a CLP per pmt) is given by  $\eta = P_{out}/P_{in}$ , with the above values it gives:

$$P_{in} = 210 \text{V} * (25 + 4.5) \mu\text{A} = 6.19 \text{mW}, P_{out} = 210 \text{V} * 25 \mu\text{A} = 5.25 \text{mW} \quad \eta = 84.7\%.$$

For the other two tensions (-70V and -900V) the currents are too low for an efficient active CLP, the  $\eta$ -values for these tensions are respectively 33% and 57%, to avoid this wasting of power and components it is better to proceed in another way.

The circuit has no single point failure in the input, but due to a large number of CLP connected to a single bus the input failure probability can be reduced separating the resistor  $R_1$  in two or three resistors connected in series.

## 1.5 Passive CLP

The currents delivered by the tensions -70V and -900V are too low for an efficient active CLP. We can conjecture to change the electronic CLP with a simple resistance that limits the short-circuit

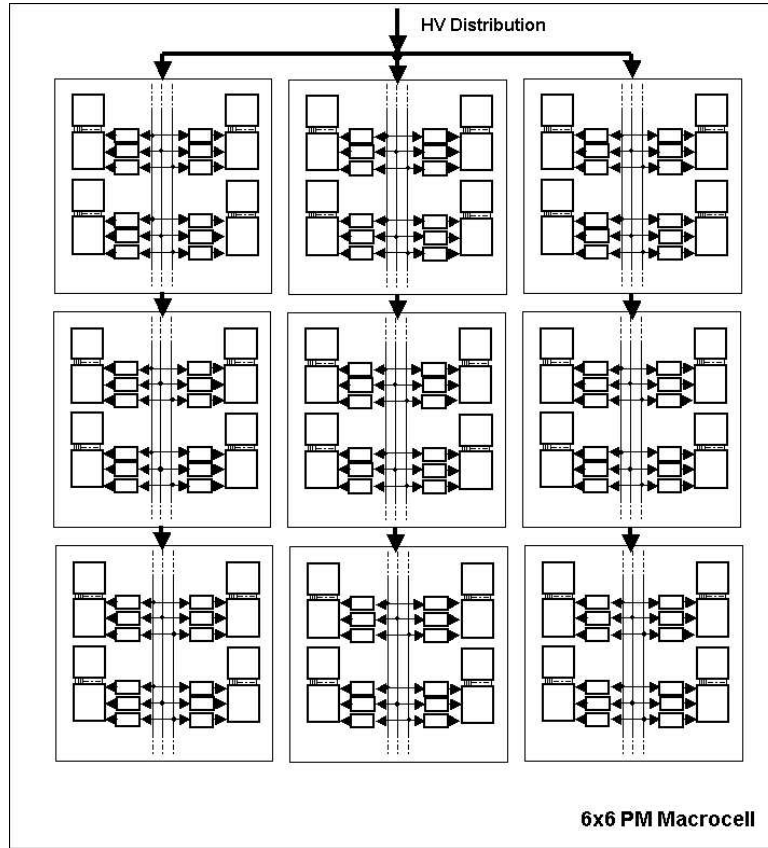


Figure 4: Draft of the three HV distribution in a macrocell (6x6 pmts)

current. Assuming a voltage drop of 1V for -70V and 9V for -900V passive protections can be implemented with efficiency of 98% and 99% respectively. These efficiency are high but the short circuits currents are high: respectively  $70\mu\text{A}$  and  $340\mu\text{A}$ . So, in presence of a large number of pmt short circuit failures the power limits of each HV elevator cannot be reached.

## 1.6 Triple HV Supply Rails Architecture

The arrangement of the triple HV supply is studied with some detail. The distribution is evidently more complex compared to the usual one with a single HV supply. The architecture of the distribution in each microcell is reported in Fig 3 considering a CLP and a VD for each pmt.

Figure 4 is a draft for the HV distribution in a macrocell (6x6 pmts).

## 2 Active VD

Types of VD composed by active elements are of some use. The need of active components is addressed to a reduction of energy absorption by the resistors of a passive VD. The standard usage of a factor 100 in the ratio of the current in the VD and that in the last stage of the pmt implies a large energy dissipation not allowed in space experiments with thousands of pmts. The active VD (AVD) of Fig. 5 can reduce these needs. The transistors are driven by low currents and keeps constant the tensions at their connections over a large range of pmt current drain. Here the transistors are in the emitter-follower configuration. The tension on the emitter is given by the base tension minus  $V_{be}$ . The base tension is given by a resistive divider.

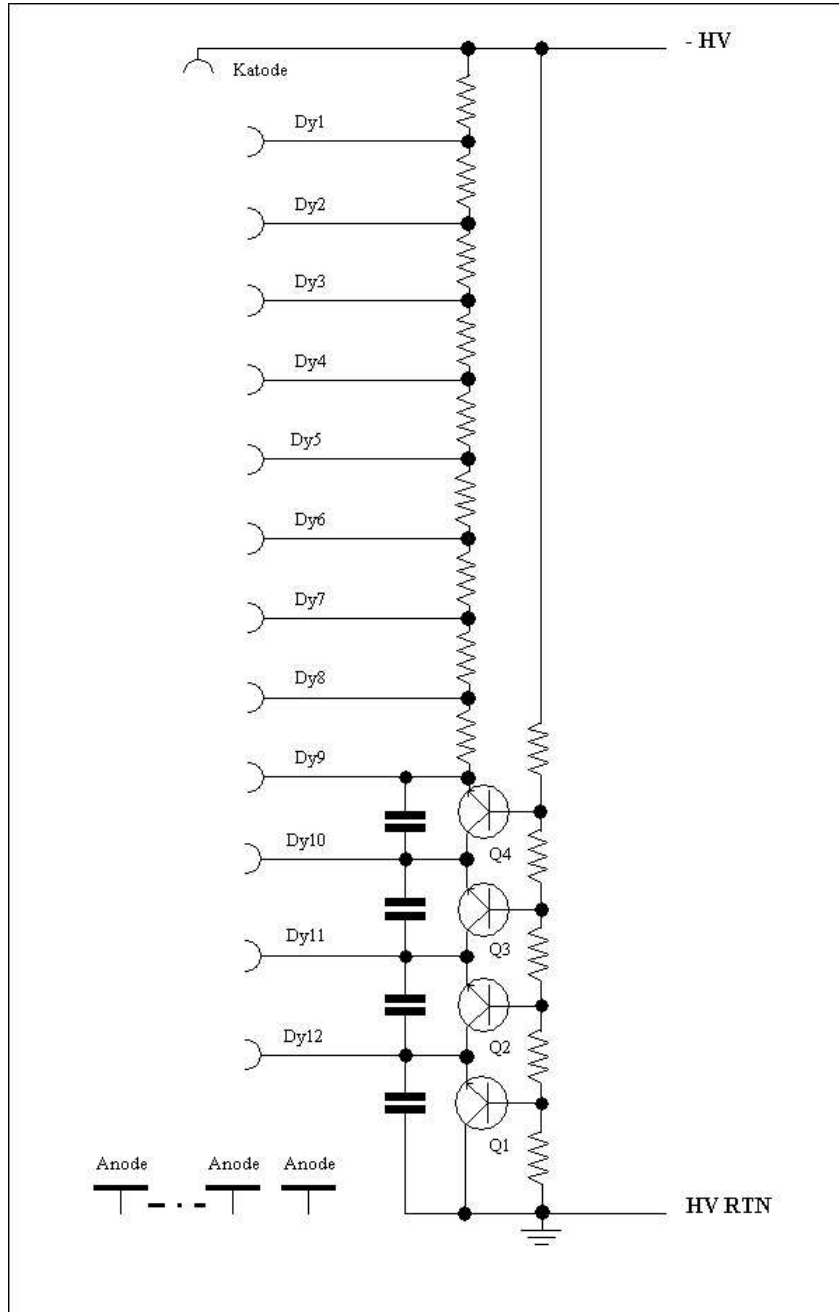


Figure 5: Active voltage divider

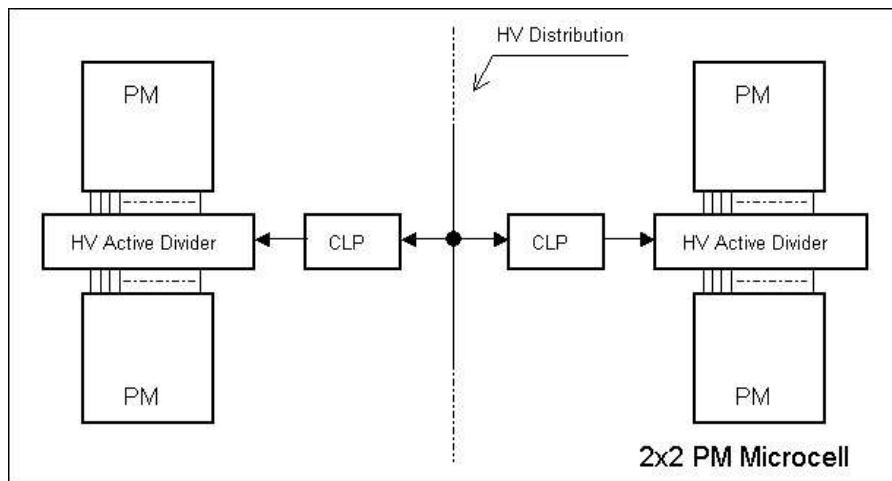


Figure 6: HV distribution and CLP

Developing the calculation for this case (with a gain  $\beta$  not less than 10) one arrive to a power absorption of 14mW per pmt and to a total consumption (over 6000 pmts) of 84 W. These numbers are higher than that with multiple HV but further optimizations are probably in order. As a simplification of the set-up we can consider a single AVD for a pair of pmts in this case a short-circuit failure in a pmt imply the loss of a pair of pmt. This implies a reduction of the total power absorption to 68W. Having to do with a single tension of -900 V, it is easier to implement a CLP for this case. Fig. 2 report the scheme for the CLP that now has different inputs and outputs, the efficiency turns out to be  $\eta = 84.8\%$ .

Total power absorption with an AVD per *pmt* 84 W

Total power absorption with an AVD per two *pmt* 68 W

Positive aspects of AVD: large linear dynamic range and the ability to cope with large variations of background light [2], o single HV elevator for a group of macrocells.

Negative aspects of AVD: more components, higher power absorption.

## 2.1 HV Supply Rails Architecture for the AVD

The architecture of the HV distribution at the microcell level is reported in Fig. 6, with an AVD for two pmts. The HV distribution in a macrocell and the CLP protections are schematized in Fig. 7. The complete set up with the expected redundancies of the HV elevators is plotted in Fig. 8.

## 3 LV Distribution

The data for the LV distribution are less critical and can be calculated globally. We will assume 2 mW/channel with  $410^5$  channels one needs 800W, evidently this is scaled by observation time. CAEN boards for these tensions are available, and 40 Boards (+redundancy ) could be requested with a total weight of kg 4. If the separation of the "analog" sectors from the "digital" sectors will be implemented, the number of requested boards can increase.

## 4 Conclusions and Future Developments

This is a preliminary estimation of the Power Supply needs for EUSO, with some exercise on the HV distributions and CLP protections. The power request of the two explored solutions is

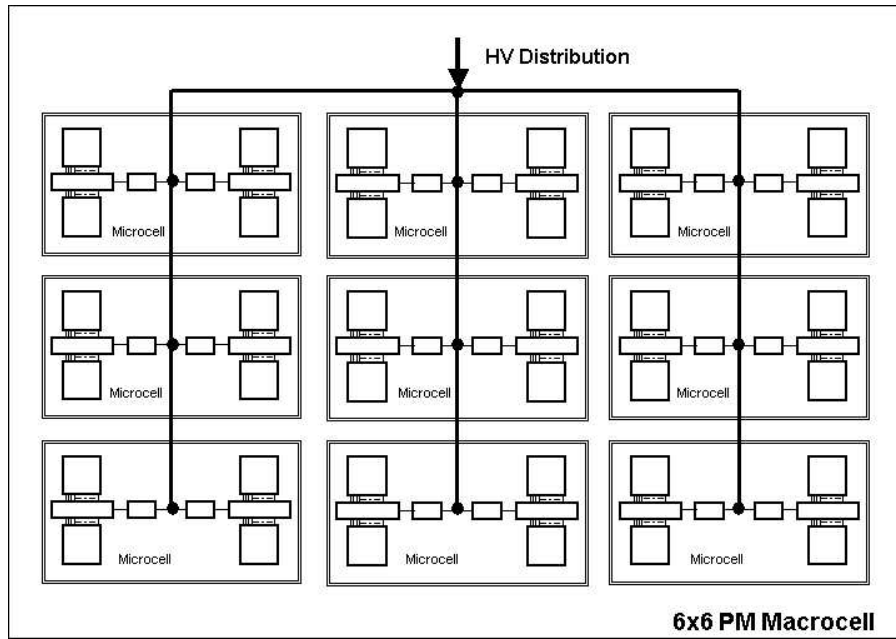


Figure 7: HV distribution in a 6x6 pmt macrocell for an AVD

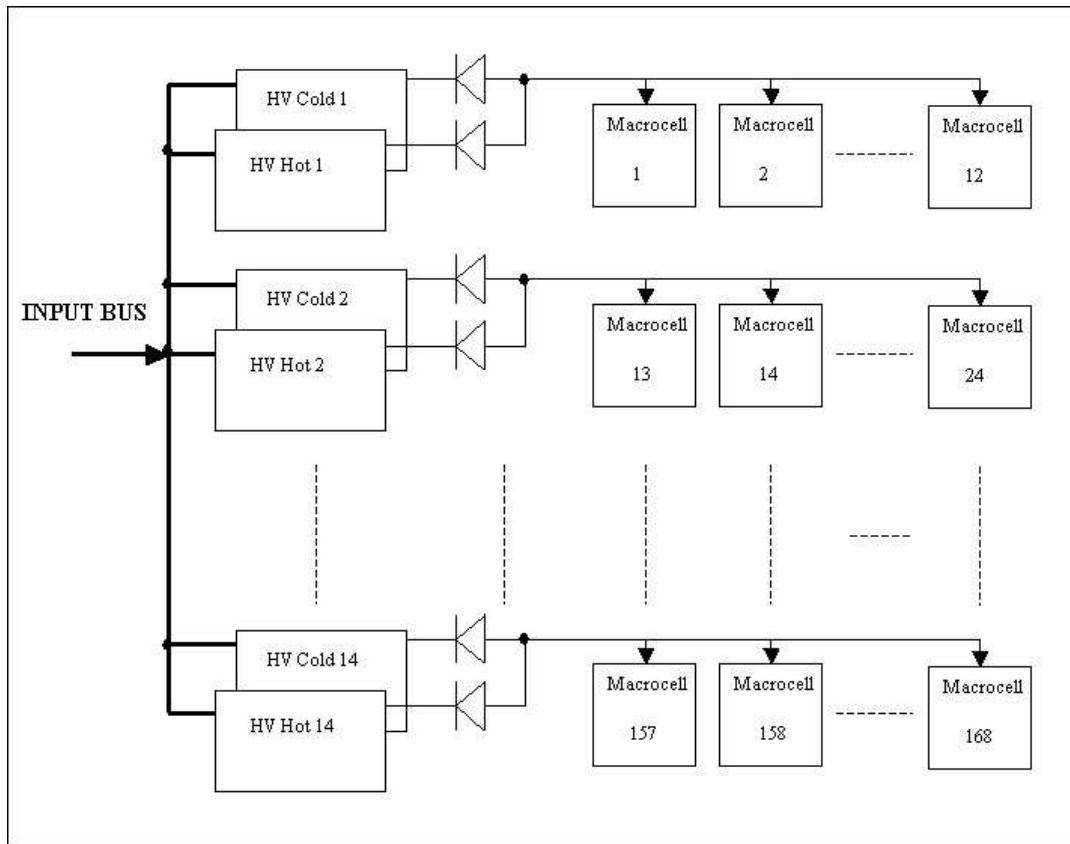


Figure 8: HV elevator arrangement for the AVD with 28 CAEN S9030 DC/DC converters



drastically reduced respect to any initial expectation [1]. The ratio of the current in the VD respect to that of the pmt is 50 giving a margin to accommodate increases of background light without risks of a pmt shutoff. The passive protections suggested for the triple HV tensions can imply an increase of the power request on each HV elevator in presence of an high rate of pmt short-circuit failures. To make any selection, an evaluation of the probability of that failure must be accessible.

These preliminary calculations assume an identical voltage drop at each step of the VD. This set up maximizes the gain, but can reduce the collection efficiencies at some critical electrode. Further calculation will be given with a more appropriate voltage steps, but detailed gains for each stage of the pmt must be obtained from the pmts producer.

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## References

- [1] M. Ameri et al. Study report on the EUSO photo-detector design. INFN/AE-01/04.
- [2] S. Argiro, D.V. Camin, M. Destro, C.K. Guérard. *Passive and Active PMT Biasing Networks*.GAP-98-063.