Proposal for a High Voltage System for the RICH

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Introduction

The present design of the RICH photon detector system consists of approximately 1500 16 anode (M16) and 1000 4-anode (M4) multi-anode PMTs. The PMTs will reside in two grid structures, one in the upper and one in the lower focal plane. Each grid structure consists of 3024 (84 wide, 12 high) square cells of 36 mm^2 size. Since the PMTs will not fill the whole structure, they will be distributed to best accommodate the expected photon density. Four multi-anode PMTs will be mounted on a 70 mm square circuit board (base-board) containing four high voltage divider chains, one for each tube. The Outer Tracker (OT) ASD08 card will be used to read out the PMT signals. All the necessary modifications to adapt the PMT signal to the OT ASD08 card will be implemented on the base-board. The base-board for the M16 will contain four connectors, all oriented vertically, for the ASD08 cards; the M4 base-boards will contain only a single ASD08 connector. High voltage to the PMTs will be supplied by a computer-controlled multi-channel power supply, distributed to groups of at least four multi-anode PMTs. Several grouping schemes are discussed in this document.

PMT Base Circuit

The Hamamatsu multi-anode photomultipliers of the R5900 series have 12 dynodes in the M16 version and 10 dynodes in the M4 version. Using a voltage distribution ratio of 1.5 : 1.5 : 1.5 : 1 …1 (higher ratio for the first 3 dynodes), a gain of 10^6 for the M16 and M4 can be achieved with a supply voltage of 700 V and 720 V, respectively, according to Hamamatsu's specifications. At a HERA-B photon rate in the RICH of 2 MHz and a gain of 10^6, the M16 produces an anode current I_a of approximately

$$16\ \mathrm{ch/PMT} \times 2{\cdot}10^6\ \mathrm{Hz} \times 10^6 \times 1.6{\cdot}10^{-19}\ \mathrm{C/electron} \approx 5\ \mu\mathrm{A}$$

The main design criterion for the resistor chain is to have a large enough bleeder current I_b in the chain to prevent loss of gain (sagging) in the last stage at high rates. The loss of gain as a function of the anode current for a uniform chain is given by [1]

$$\frac{\Delta G}{G} = \frac{I_a}{I_b}\,\frac{n(1-\delta)+1}{(n+1)(1-\delta)} \approx \frac{I_a}{I_b}\ ,$$

where n is the number of stages and δ is the secondary emission factor (or gain per stage). For our application,

$$\delta = \sqrt[n]{G} \approx 3.16.$$

For example, a ratio of 20:1 for I_b:I_a ensures less than 5% drop in gain in the hottest region (2 MHz at a gain of 10^6). This conclusion is still true if the divider chain is slightly non-uniform. The capacitors at the last stages supply the transient current for individual pulses. A typical pulse at the final stage of the PMT has 0.16 pC of charge with a pulse length exceeding 1 ns. The present design of 10 nF in the last stage, which furnishes 5 pC in 1 ns, is quite adequate.

Measurements

To test the dependence of the gain at high rates on the value and composition of the resistor chain, extensive tests with the M16/ASD08 combination were done at Ljubljana [2]. Figure 1 shows the rate vs. voltage behavior for different simple divider chains, indicating that a good plateau of 7.5 MHz can be achieved with 560 kΩ resistors (bleeder current ≈ 100 μA). The preferred divider will use 1 MΩ resistors for the first three dynodes to improve the single photon spectrum and 560 kΩ resistors for the remainder. The 10 nF capacitor across the last dynode also improved signal shape.

Preliminary tests at Ljubljana of M4 PMTs from the first shipment of 50 show that the problem with high cross-talk, as it has been observed in an earlier prototype, has been fixed by Hamamatsu. Values for the resistors and capacitors in the M4 divider chain will be similar

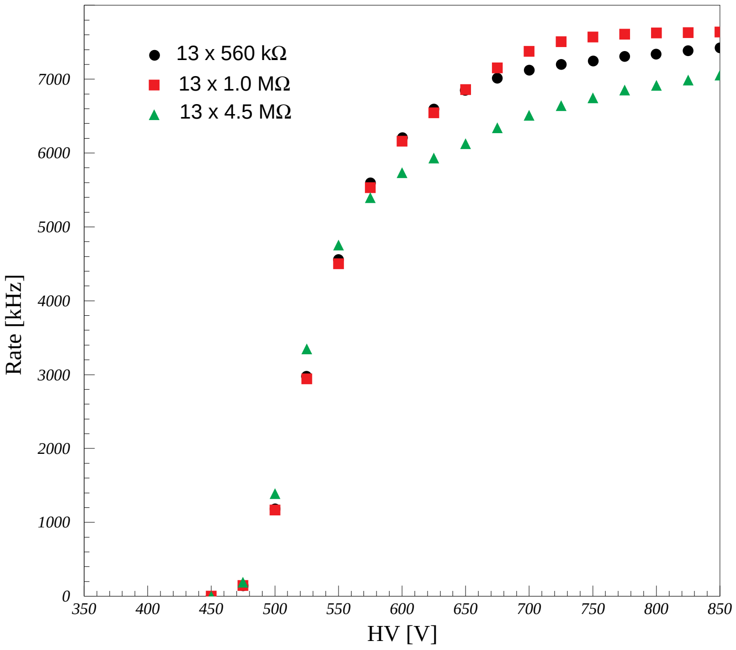

Figure 1: High Rate behavior of the M16 for different bleeder chains .

to those used in the M16.

Expected PMT Bleeder Currents

The bleeder current of a M16 PMT with a 8.60 MΩ divider at 700 V will be 81 µA plus about 5 µA of signal current for a 2 MHz photon rate. Our goal is to run the M16 at the lowest possible voltage to reduce the aging damage at the last dynode. Therefore, we can assume supply currents of less than 100 µA per M16 base.

Assuming a similar photon rate per channel for the M4's (near the granularity boundary), we expect only 1/4 of the anode current and thus might operate with a bleeder current lower than the 100 µA assumed for the M16.

Choice of High Voltage Power Supplies

The main requirement for a high voltage system for the RICH is a large number of channels with independently controllable voltages up to approx. 1200 V. Currents per channel should be in the mA range; individual current measurement is not essential due to the constant load from the resistor chains. To our knowledge two high density systems are available on the market, one from LeCroy and one from CAEN.

CAEN

The CAEN system, called SY 527, consists of a 19" wide mainframe with full front-panel control. Remote operation is realized through a fast serial connection (high-speed CAENET) or a VT100 terminal (see Figure 2). Up to 10 different multi-channel supply boards can be plugged into the back.

Two kinds of boards can be considered for the RICH: supply boards with 16 independent HV channels and distributor boards with 24 programmable HV channels. The 16 channel supply board, Model A733A, delivers a higher current and allows full monitoring and control of voltage and current for each channel independently. The distributor board, Model A938A, has a single built-in HV supply with full control/monitoring of voltage and current. Only the voltage of the individual channels can be monitored. The voltage of each distributed channel can be set up to 700 V below the supply voltage. Table 1 lists the main features of the two CAEN HV boards. Both boards allow programming of ramp up/down rates and setting of current limits. The high voltage output is supplied through a single multi-pin connector.

The expertise and track-record of the Italian company CAEN is very good. The 527 system is being used successfully by the HERMES experiment at DESY and by many others at CERN. At UH we had extensive experience with the predecessor model SY 127 from CAEN

Table 1: Properties of two CAEN high voltage boards for the SY527 main frame.

Model	Polarity	Type	Ch	Supply Voltage	Voltage Drop	Max. Current	Voltage Resolution	Current Resolution	Max. Ripple	Price DM
A733AN	neg.	supply	16	0–2500 V	–	3.0 mA	0.2 V	1 µA	30 mV	3990
A938AN	neg.	distrib.	24	0–2550 V	0–700 V	1.2 mA	0.2 V	2 µA*	10 mV	3380

* only on the primary supply channel

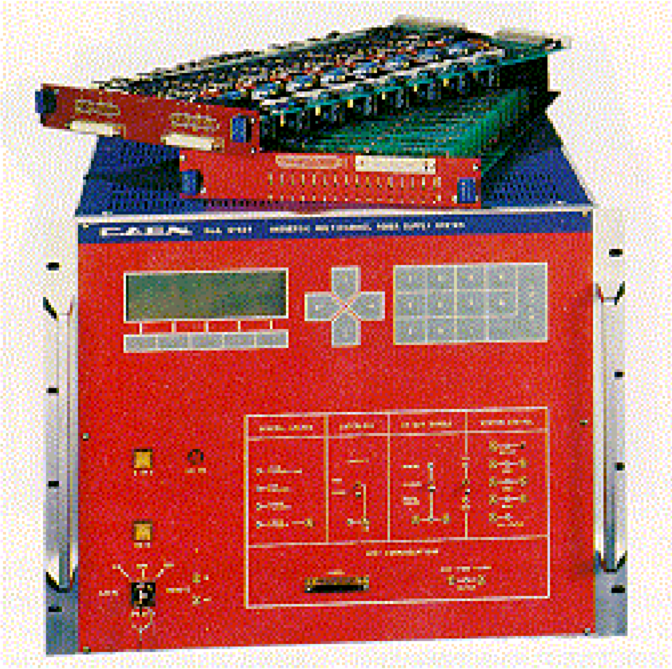

Figure 2: The CAEN SY 527 High Voltage System main-frame and two multi-channel supply boards.

of which we used a five mainframe 200 channel setup without any trouble for over five years at the SMC experiment at CERN.

The price, quoted to us, for a SY 527 mainframe including all communication options is 16 120 DM; a system fully equipped with ten A733 modules (160 ch total) costs 56 025 DM (350 DM/ch) or 49 920 DM when using ten A938 modules (240 ch total, 208 DM/ch) [3].

LeCroy

LeCroy offers a similar system (VISyN 1450); their mainframe can be equipped with 16 plug-in boards. The only board that will meet our requirements is the model 1461 which has 12 individually controllable channels delivering up to 3000 V and 2.5 mA. No suitable distributor boards exist from LeCroy. The mainframe has no front-panel controls or displays – control is only via VT100 or ethernet/ARCNET. The 2.5 mA output current can only be achieved at voltages larger than 2800 V, below 1000 V only 1 mA is available (see Figure 3 right). All high voltage outputs are using a SHV type connectors. The price for a standard 1458 mainframe with communication module is 15 360 DM. The cost of a fully equipped system with sixteen 1461N boards (192 ch total) is 60 320 DM (314 DM/ch) [4]. The parameters of the LeCroy high-voltage board are listed in Table 2. A picture of the system is shown in Figure 3.

Table 2: Properties of a suitable high voltage board for the LeCroy 1458 main frame.

Model	Polarity	Type	Ch	Supply Voltage	Voltage Drop	Max. Current	Voltage Resolution	Current Resolution	Max. Ripple	Price DM
1461N	neg.	supply	12	0–3000 V	–	2.5 mA	1 V	1 µA	100 mV	2810

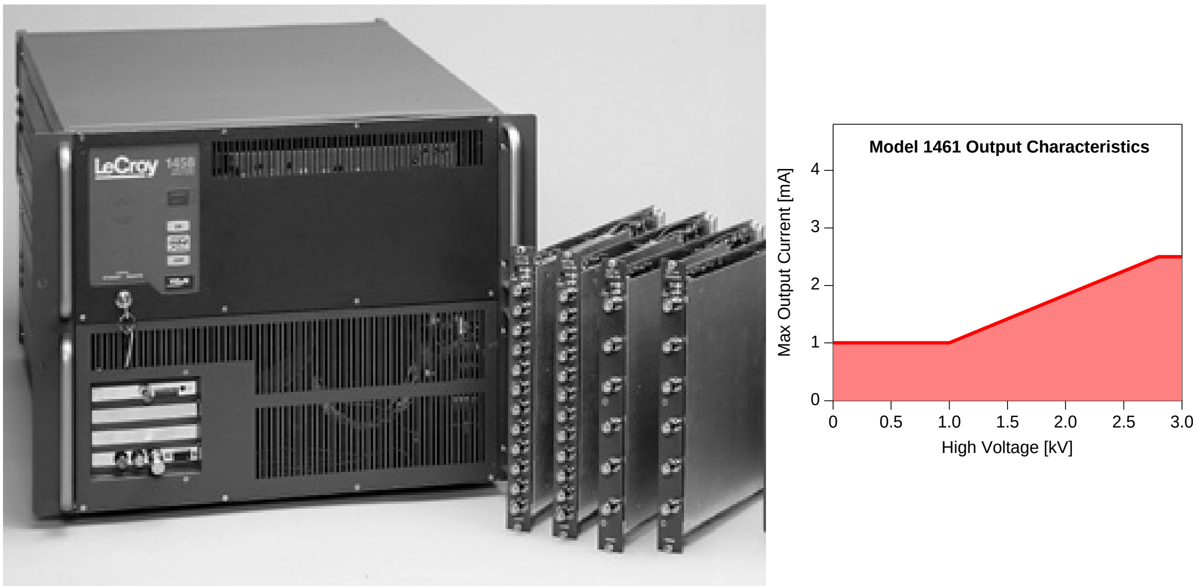

Figure 3: The LeCroy high-voltage mainframe (1458) and two 6 and 12 channel output boards (left). Output characteristics of the model 1461 HV board (right)

Recommendation

Many other subdetectors in HERA-B (Muon, TRD, Outer and Inner Tracker, High-pT) have opted for the CAEN high voltage system because CAEN offers more than 20 different plug-in boards. This versatility allows us to employ a single high-voltage system for HERA-B. Having only one system keeps the programming overhead for the slow control to a minimum, and reduces the spares inventory. The reduced maximum current of 1 mA below 1 kV for the LeCroy solution allows only a total output of 192 mA per mainframe, compared to 288–480 mA for a CAEN main-frame. Even though the prices for the CAEN and LeCroy systems are comparable, only CAEN allows the use of economical multi-pin AMP connectors and avoids the very expensive SHV (25 DM/ch) connectors.

We therefore recommend the CAEN 527 system for the RICH high voltage.

Grouping of High Voltage Channels

Assuming a bleeder current of 0.1 mA per M16 and per M4 multi-anode PMT, we have to supply the following currents:

M16: 1500 × 0.1 mA = 150 mA **M4:** 1000 × 0.1 mA = 100 mA **Total = 250 mA**

Assuming that we will use only one fully equipped SY 527 main frame, the total current could be supplied by ten A938 distributor boards (10 × 24 × 1.2 mA = 288 mA) as well as by ten A733 boards (10 × 16 × 3 mA = 480 mA) or a mixture of both.

Past experiences with PMTs indicate that the long-term failure rate of PMTs is quite low. In our application, the PMTs are operated at a relatively low gain, thus enhancing their chance of surviving the entire HERA-B running period without failure. Therefore, it is reasonable to

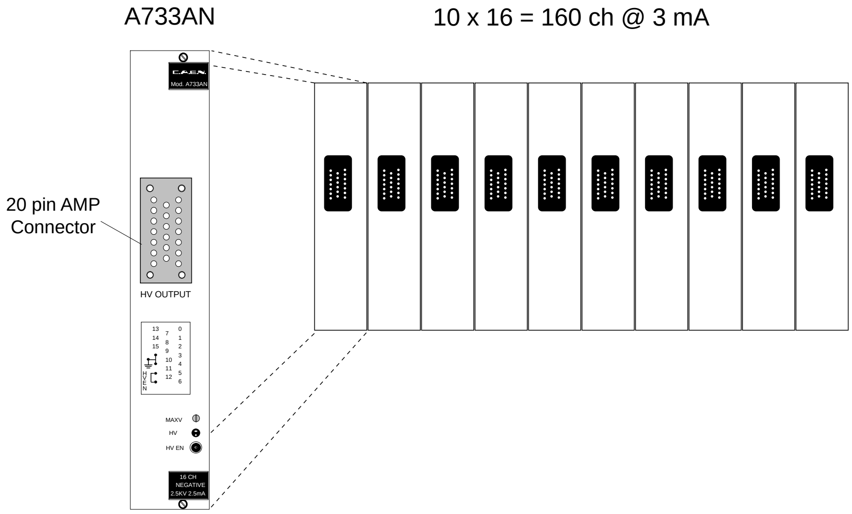

Figure 4. View of theA733 high voltage supply module front panel and arrangement in the SY527 main-frame.

group several PMTs to one HV channel. The main drawback of grouping is that more than one PMT will have to be turned off if one PMT in the group fails. The grouping, therefore, has to be optimized to minimize the loss of acceptance if a failure does occur.

The smallest HV group is a four PMT base-board with either 4×M16 or 4×M4 PMTs. Each base-board draws 0.4 mA bleeder current. There will be 375 4×M16 and 250 4×M4 base-boards, a total of 625.

If one groups four base-boards together, one needs 157 high voltage channels with 1.6 mA output current. This simple 4:1 scheme ideally matches a configuration with 10 A733 CAEN supply modules with a total of 160 channels. If one increases the total resistance of the M4 divider by 20%, so the bleeder current drops to 83 µA per PMT, all 250 4×M4 base-boards can be served in groups of 8 by just 32 channels with 2.66 mA output current. The remaining slots can house eight 24 channel A938 distributor boards for a total of 192 outputs or eight 16 channel A733 modules for a total of 128 outputs. In the first case one would use a 3:1 reduction (3 × 0.4 mA = 1.2 mA/ch) in the second a 2:1 reduction (2 × 0.4 mA = 0.8 mA/ch) of base-boards to high voltage channels.

Because a configuration with all 16-ch 3mA modules gives us more flexibility due to the higher output current per channel we will *recommend a solution using ten A733 high voltage supply modules* in one Sy527 main-frame as shown in Figure 4.

Cabling

A suitable high voltage cable is available in the DESY store (Type HTC-50-1-1, DESY# 11900). It’s a halogen free coaxial cable of 3.3 mm outer diameter with partial discharge screens rated at 5 kV. The price for small quantities is 1.33 DM/m, but the price might drop for large quantities. In an optimal scheme (one cable for each 4x4 base-board) about 650 cables of this type (including spares) – half from the upper and half from the lower focal plane – would join at the bottom of the central platform and go using the cables trays to the second floor of the electronics hut. The cable bundle is easy to handle because it only occupies an

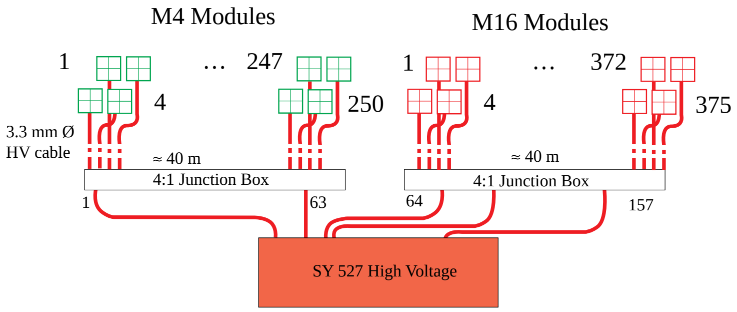

Figure 5: HV cabling of PMT modules utilizing a junction box near to the HV supply.

area of 56 cm^2. The junction box will be placed near the CAEN SY 527. From the junction box a 4:1 reduced set of cables (156) will connect to the power supply modules in the back of the SY527 main-frame.

We will use cheap circuit board mountable connectors, Amphenol Universal Power (UP) connectors, No.'s 176271 & 176975 (approx. 1 DM/pair), to connect to the base-board and the junction box. Between the junction box and the A733 we will use the appropriate AMP 20-pin high voltage connector on both ends of the short 16-wire bundle. The price for this type of multi-pin connector is 36 DM. A rough schematic of this layout is shown in Figure 5.

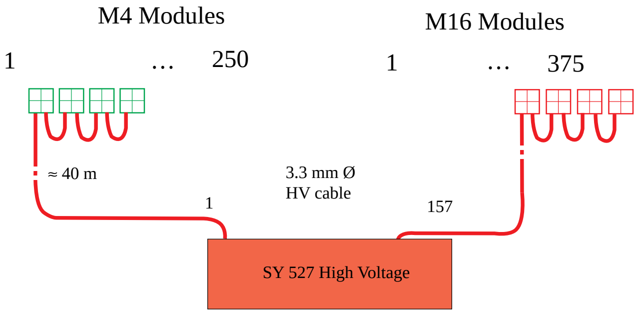

Figure 6. HV cabling using one cable for 4 base boards and a daisy chain between.

The current layout of the M16 and M4 base-boards foresees two parallel UP connectors for high voltage. Only one would be needed if we utilize the 625 cable scheme (4 PMTs, one cable). To save on cabling costs HERA-B decided to daisy-chain four base-boards at the focal plane using short UP jumpers and only use one long cable for groups of 4 base-boards. This alternate cabling scheme is illustrated in Figure 6.

Arrangement of PMT modules on the Focal Plane

It is planned to equip both the upper and the lower photon window on the radiator tank with a set of seven supermodules, 36 PMT cells high and 12 wide. A PMT cell is a square of 36 × 36 mm^2 that can hold either a M16, a M4 or a single anode PMT. The 2500 multi-anode PMTs that HERA-B has ordered would occupy only about 41% of the cells in the supermodules.

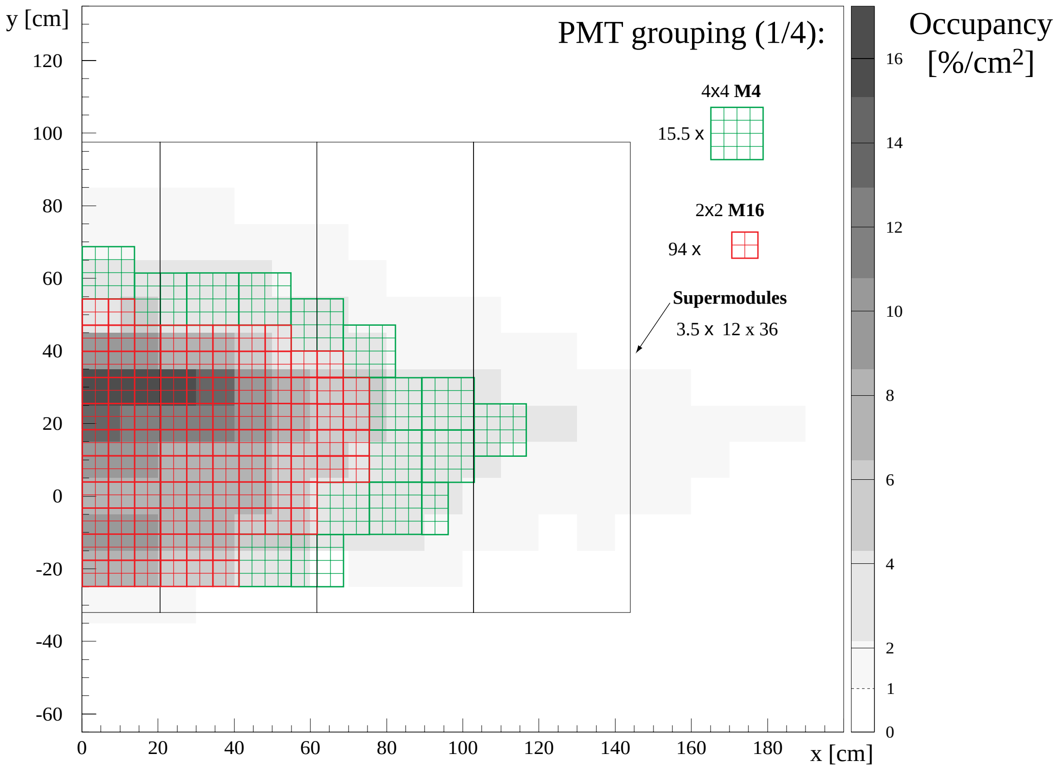

Figure 7: Expected occupancy in (shaded area) and possible placement of M16 (red) and M4 (green) PMTs and outline of the supermodules (black). Eight M16's and M4's will be powered by a single HV channel.

Shown in Figure 7 is, based on Thorsten Oest's occupancy plot, a possible arrangement of PMT modules in one half of a focal plane. Shown as thin black rectangles is the supermodule structure. The red squares represent the M4 modules, grouped 2×2 on a base-board, four of those base-boards (16 M16's) would be powered by one HV channel. The green squares are the M4 modules, 2×2 PMTs. Again four of those (16 M4's) will be powered by one HV channel.

Mode of Operation

We plan to run large groups of ASD08 cards at a relatively high common threshold. The only variable parameter in the operation of the PMTs is therefore the high voltage. Hamamatsu guarantees a gain variation of less than a factor of five. Therefore, all PMTs will be tested and grouped according to their voltage dependence. Each group will be given a suggested operating voltage.

Monitoring

Groups containing 16 PMTs will be powered by individually controllable HV channels of the A733 board. Their voltage can be set anywhere between 0 and 2500 V and the current can be monitored with 1 µA resolution for each channel. A group draws about $16 \times 90 = 1440$ µA bleeder current. With beam the current can increase by 5 µA (1 µA for M4) per PMT, or 80

(16) µA total. This makes detection of malfunctioning voltage divider chains even under operating conditions possible.

Failure Modes

PMTs are much less likely to fail in a mode which forces them to be turned off than wire chambers. If other reasons like arcing on the base-board or in the HV-cables trip off of a HV channel, a group of 16 M16 or M4 PMTs will be lost initially. Three quarters of this could be recovered by manually disconnecting the faulty cable/base-board at the junction box in the electronics hut. A single disconnected base-boards of M16 (M4) represents only 0.23% (0.06%) of the total number of channels; without the junction box, a disconnected HV channel represents a loss of 0.91% (0.22%). Other failures like unplugged or faulty PMTs or bad ASD08 cards can only be detected by looking at the event data.

Concluding Remarks

This document represents our current thinking of the overall plan for the PMT high voltage system. Some of the conclusions are still preliminary. The first 10 prototypes of a 2xM16 base-board have arrived and are in the process of being tested. In spite of these uncertainties, the solution we propose is within our budget, and can be built on time.

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[1] See, e.g., W. R. Leo, “Techniques for Nuclear and Particle Physics Experiments”, Springer Verlag, 1987, p.178.

[2] S. Korpar, R. Pestotnik, P. Krizan, “ASD8 Chip Tests with a Hamamatsu Multi-anode PMT”, IJS -DP-7615, January 1997

[3] CAEN 1997 Short Form Catalog, Plein & Baus GmbH quotation 03116-97 from March 20, 1997.

[4] LeCroy VISyN High Voltage Systems (March 1996); LeCroy Heidelberg, LRS Preisliste (Feb. 1. 1997).