H1-08/96-486

Adjustment of the High Voltage for the H1 – Spacal

Andreas Meyer (DESY)

Abstract

In April 1995 the new lead/scintillating-fibre calorimeter 'Spacal' was installed in the backward region of the H1-Detector. It consists of two sections – an electromagnetic part with 1192 cells and a hadronic part with 136 cells. Each cell is read out by a Hamamatsu Fine-Mesh-Photomultiplier-Tube (PMT). In order to achieve equal response from each of the cells each PMT must be supplied with an individual High Voltage.

A detailed description of the Spacal can be found in [1], [2] and [3]. Information about the photomultipliers can be found in [4].

In the following the Spacal HV System is described. The procedure used to determine and set the optimal High Voltage is presented. In this context the so called method of LED-photo-electron-statistics is especially focused on. An Appendix provides informations about technical details. The High Voltage Settings used for the data taking are tabulated.

1 The High Voltage System

A schematic view of the Spacal High Voltage System is shown in figure 1. The Spacal consists of 98 supermodules (electromagnetic and hadronic parts), each containing 16 cells. Each supermodule is equipped with a HV-Distribution-Board. The Distribution Boards are provided with High Voltage by a CAEN Power-Supply [1]. One CAEN-channel supplies 16 PMT-cells connected to one HV Distribution Board. The Distribution Boards contain opto-couplers with which the voltage from the Power Supply can cellwise be reduced by up to 350 Volts. An 8 bit serial bus connection between the boards and the OS/9 station `h1cal10` allows transmission of reduction constants in a range between 0 and 255, resulting in a step width of $350V/2^8 \approx 1.4V$.

The CAEN Power Supply is controled from a computer 'OS/9 `h1cal5`'. Since the HV Distribution Boards can not be monitored (i.e. the High Voltage can not be

[1]Mainframe 'CAEN SY 527'

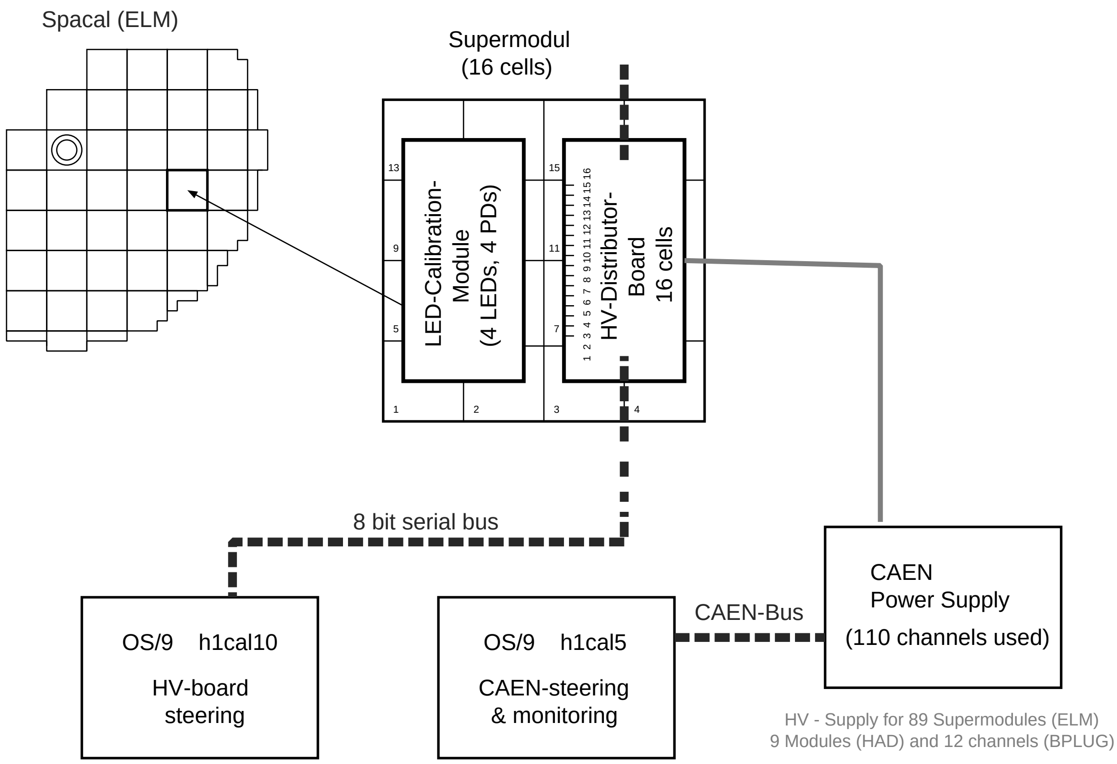

Figure 1: The High Voltage System consists of a CAEN Power Supply serving 89 HV Distribution Boards where the voltage for 16 cells is individually reduced.

measured at cell level) the monitoring of the High Voltage is performed at the CAEN only. A monitoring program checks the sums of the currents drawn by 16 cells in a supermodule and the voltage provided to the HV Distribution Boards[2].

2 HV-Adjustment

2.1 Goals of the Adjustment

The gain of the photomultipliers strongly depends on the applied voltage. Test measurements have shown that for the photomultipliers used in the Spacal the dependence can be parametrized by $G \propto (U - U_0)^a$ where the distribution of the exponent a has a mean of about 6 and a spread of $\sigma = 0.2$ [4]. Each photomultiplier must be provided with an individual and precise voltage in order to make the gains equal. Equal gains are necessary for two main reasons:

- Coarse equalization is necessary in order to ensure the measurement of the signals throughout a large energy-range from a few MeV up to 30 GeV. Primarily

[2] see Appendix

the signal-to-noise ratio must be optimized for an effective background suppression as well as for the measurement of low energies in physics events, i.e. the signals must be large enough to allow a precise and efficient measurement of the energy and time of minimally ionizing particles (MIPs), e.g. muons. MIPs longitudinally traversing Spacal deposit an average energy of 400 MeV, transverse MIPs about 50 MeV per cell. On the other hand the gain must be small enough to measure large energies up to 27.6 GeV (electron beam energy) within the ADC range.

- High precision equalization is needed for the Spacal Level-1 Trigger. The Spacal-Trigger (IET) works with summed analog signals of arrays of 16 cells around the electromagnetic cluster. The signals, without further correction, are compared with a discriminator threshold which corresponds to a certain energy [3] [5]. The requirement of sharp trigger thresholds (maximal trigger efficiency at minimum trigger rate) can only be achieved if the PM gains are equal. The highest precision is needed in the central region around the beampipe, because here both the beam gas and the photoproduction background are very high and strongly increasing as the energy decreases.

Several independent calibration methods were adopted to adjust the High Voltage, namely

- the use of the photo-electron-statistics of the PMTs (described below),
- the use of cosmic muons [9],
- the use of halo muons [10],
- and the use of the kinematic peak method [6] [7] [8].
- Methods which use events with two electromagnetic clusters in the Spacal (e.g. QED-Compton events [11] π^0 [12], J/Ψ) were used for cross checks. Investigations whether these methods can be used for the determination of corrections are still on-going.

In this note we discuss only the LED-photo-electron-statistics method in detail. For the other methods references are given.

2.2 Calibration by LED-Photo-Electron-Statistics

Photo-electron-statistics is the dominant contribution to the resolution of a photomultiplier. It is specifically dependent on the number of photo-electrons produced at the photo cathode. As a first approximation the mean $\bar{A}$ of the distribution depends only on the number of photo-electrons N_{e^-} produced at the photocathode and the

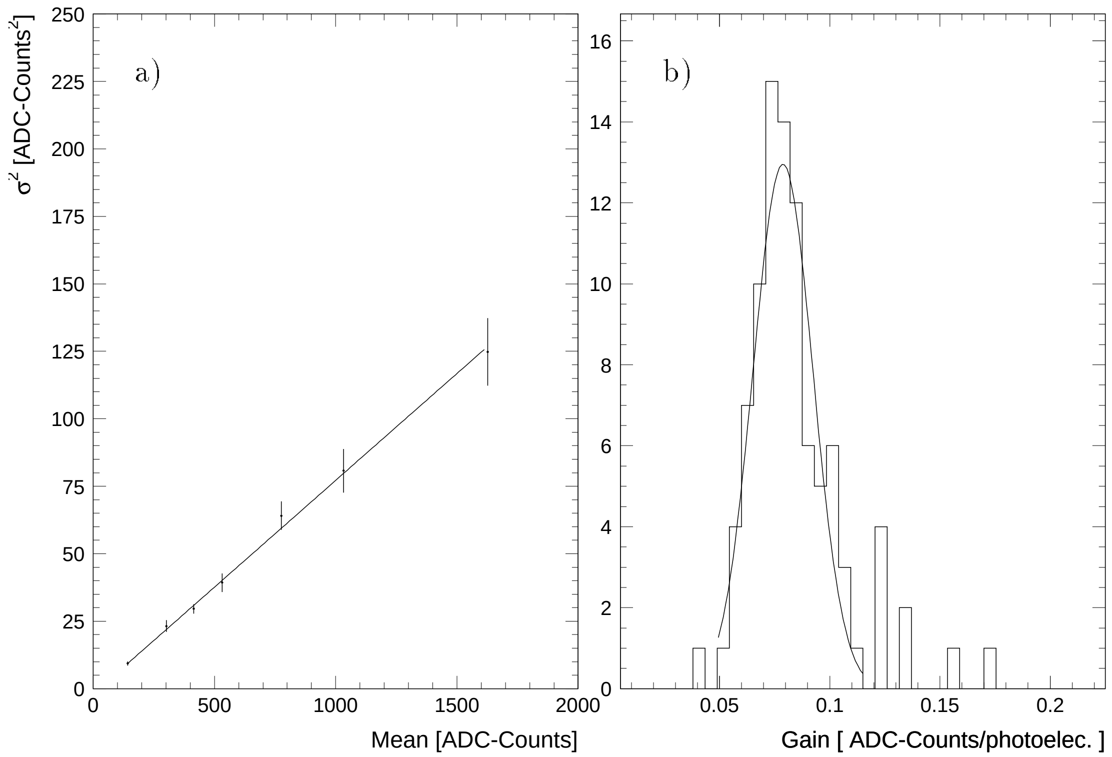

Figure 2: a) The gain of a PMT can be determined using the LED-system at different lightintensities and measuring the slope $d\sigma^2/d\bar{A}$. b) The spread of the correction constants derived by the LED-photo-electron-statistic reflects the systematic error of this method of 15 to 20 %. The tails are due to PMTs which do not fit into the available HV-Board range.

gain G of the PMT. It satisfies the relation $\bar{A} = GN_{e^-}$. The statistical fluctuation of the number of photo-electrons causes the width σ of the distribution to obey the equation $\sigma^2 = G^2 N_{e^-}$. Combining the two expressions one obtains

$$G \propto \frac{d\sigma^2}{d\bar{A}}.$$

This means that the gain of a PMT can be measured by varying the length or intensity of the light input.

The Spacal-LED-System[13] provides a source by which the behaviour of the PMTs can be studied. Its main purpose is the monitoring of short term gain fluctuations of the PMTs. By flashing the light emitting diodes (LED) at a constant intensity and measuring the response of the PMT one obtains a Gaussian distribution which is related to the gains of the PMTs.

For the measurement presented here the intensity of the light pulse was varied in seven steps successively changing the pulse length of the LED. At each step 500 LED light pulse events were accumulated.

In fig. 2a) the width σ^2 is plotted versus the mean $\bar{A}$ for each of the seven steps.

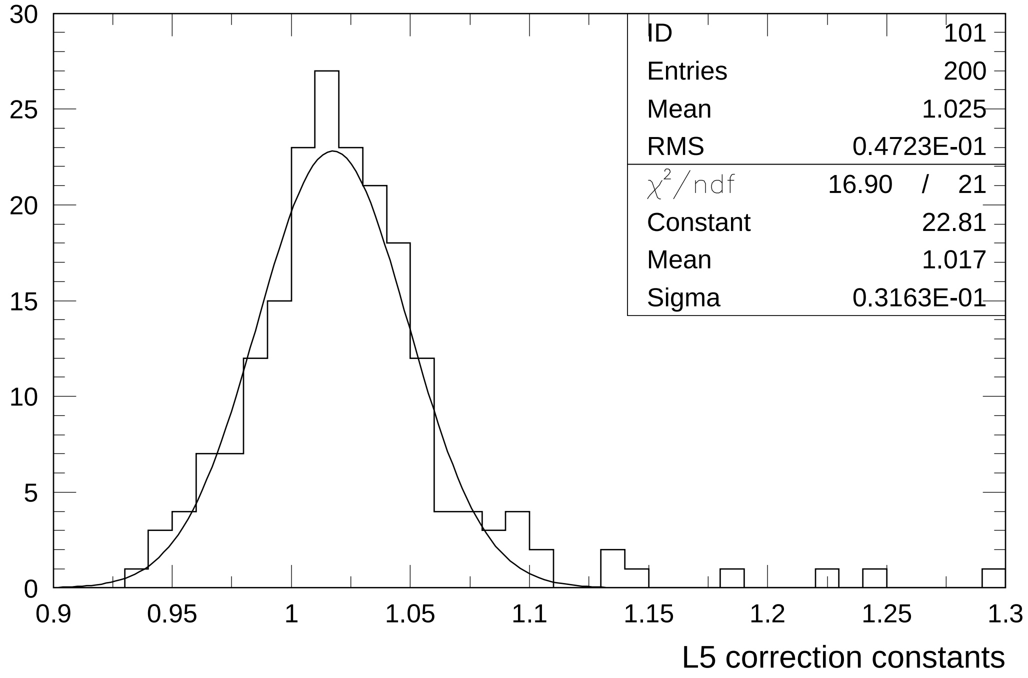

Figure 3: Correction constants applied to the data taken with the final voltage adjustment during the reprocessing. The width indicates the deviation from an ideal adjustment of the PMT gains.

The gain is given by the slope $\frac{d\sigma^2}{dA}$ which is determined by a linear fit. The error bars indicate the error of the squared widths of the distributions.

Fig. 2b) shows the distribution of the gains for 96 channels. The fitted curve is a Gaussian with a spread of $\sigma/\bar{A} \approx 20\%$. The data shown in this plot were taken in November 95 when the voltages were already adjusted on the 3% level using the results of the kinematic peak analysis. Therefore the width of the distribution represents the systematic error of the LED-photoelectron statistics method. It has four major components:

- The stability of the LED system[3]. Any instability has a large effect on the width of the Gaussian pulse distribution (e.g. temperature changes caused drifts during the measurements).
- The light-coupling between LED and PMT is different from the scintillation-fibre-PMT coupling of the light produced by charged particles in the lead/fibre-matrix.
- The error of the linear approximation.
- Additional width due to dynode gain correction factors.

[3]In normal running the stability of the LED is monitored by photodiodes. In this analysis however the photodiode information was not used.

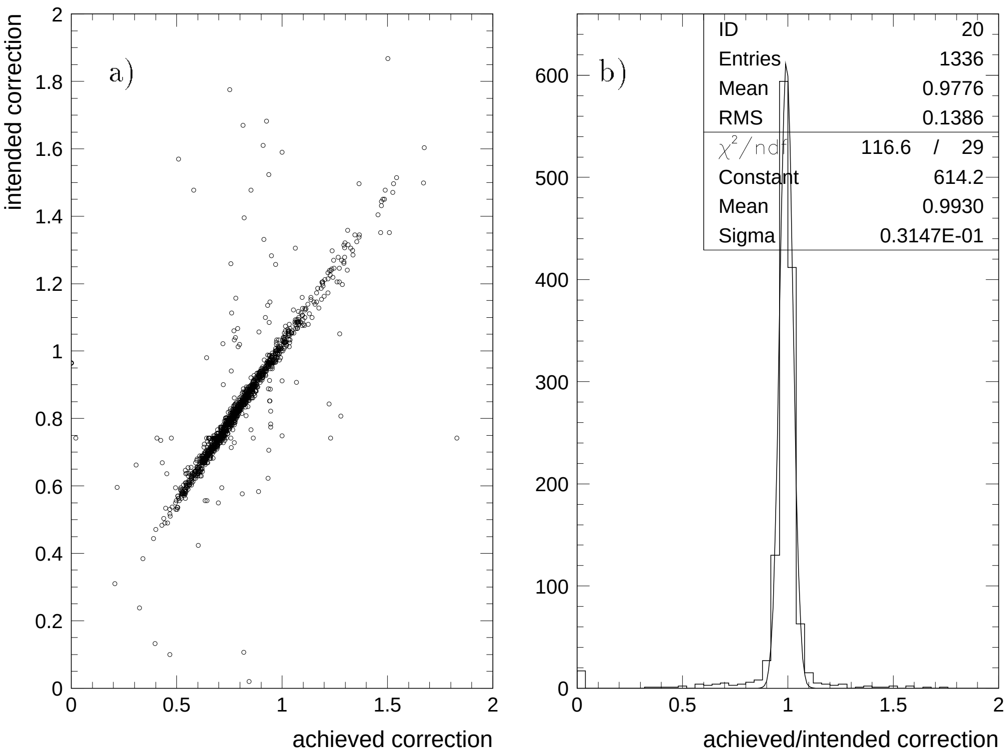

Figure 4: a) Correlation between the intended and the achieved correction. The points very far outside the correlation are due to the limitation of the HV-range in the Distribution Boards (see text). b) Ratio between the intended and the achieved correction. The width $\sigma \approx 3\%$ reflects the accuracy of the $G \propto U^6$ estimation. The tails correspond to the non correlated entries caused by the HV range problems.

The tails of the distribution are due to PMTs which do not fit into the range of the respective HV Distribution Board. During the 1995/1996 shutdown those PMTs were exchanged.

The method of the LED-photo-electron-statistics has proven to be a fast and simple way to equalize the gains of the PMTs. Its application led to a first coarse adjustment of all Spacal photomultipliers in June 1995.

During the following months, the level of adjustment was improved by exploiting also the other calibration methods mentioned above. In the beginning of September 1995 a relative equalization of the uncorrected PMT-signals of better than 5% for the whole Spacal was reached. At this time the method of the kinematic peak, which is the most precise, was limited by statistical reasons to the central region of the Spacal (up to cell number 255 at a radius of about 30 cm). Outside this region cosmic muons, since there was no statistical limitation for these data, gave a better precision of about 5%[9]. The level of adjustment is illustrated in figure 3. It shows the distribution of correction factors derived from the kinematic peak which was applied during the

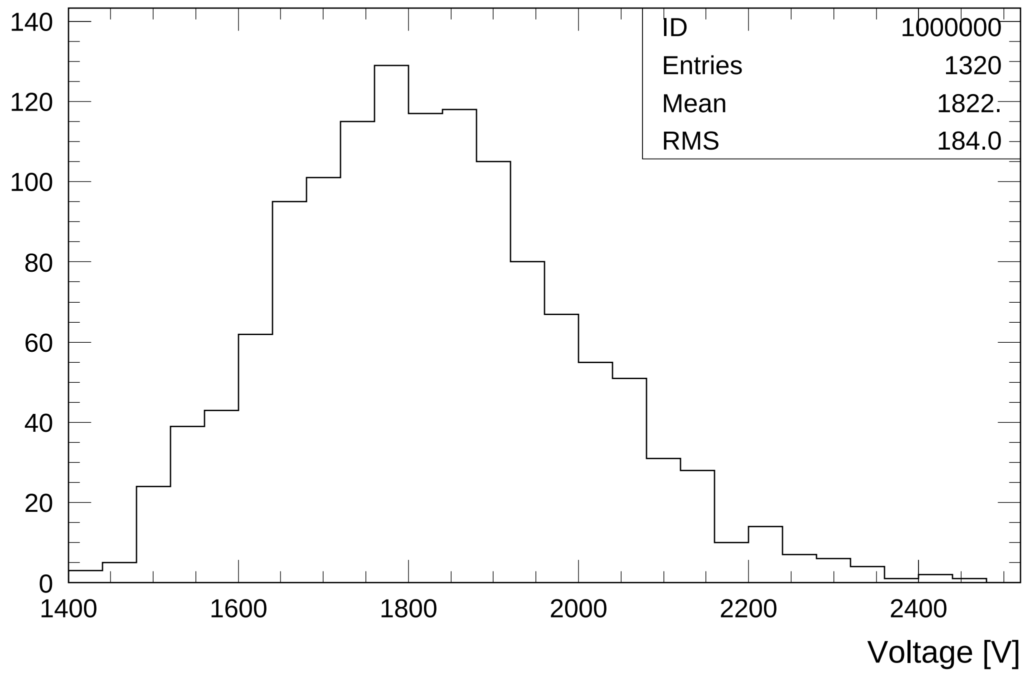

Figure 5: Final distribution of the adjusted voltages (in 1995).

reprocessing of the data[4]. The width of the distribution indicates that the gains of the photomultipliers in the central region are matched to each other at a level of 3%. The absolute scale is not considered in this plot.

2.3 Determination of the High Voltage

New sets of High Voltages were determined from the calibration constants using the relation $G \propto U^6$. The technical details of the calculation and setting of the voltages are described in the Appendix. The change of the gains when applying the corrected voltages was measured using the LED-System. Comparing the new gains to the calibration constants it was found that the gain corrections achieved by this method differ from the intended gain change by a σ of 3%. In fig. 4 the correlation between the intended gain change and the gain change achieved using the relation of the U^6-law is shown. In a) the calibration constants are plotted versus the gain change after the HV-correction, in b) the projection along the correlation is shown. There are a few entries which show a bad correlation. They are due to the limitation of the HV-Distribution-board-range of 350 Volts. These are cases when not all cells can be provided with the required voltage. During the 95/96 shutdown photomultipliers that clearly did not match the voltage level in their supermodul were interchanged in order to reduce this effect.

Figure 5 shows the rather large spread in the final distribution of the adjusted voltages.

[4]For direct comparison between uncorrected and corrected energy distributions see [8] p12.

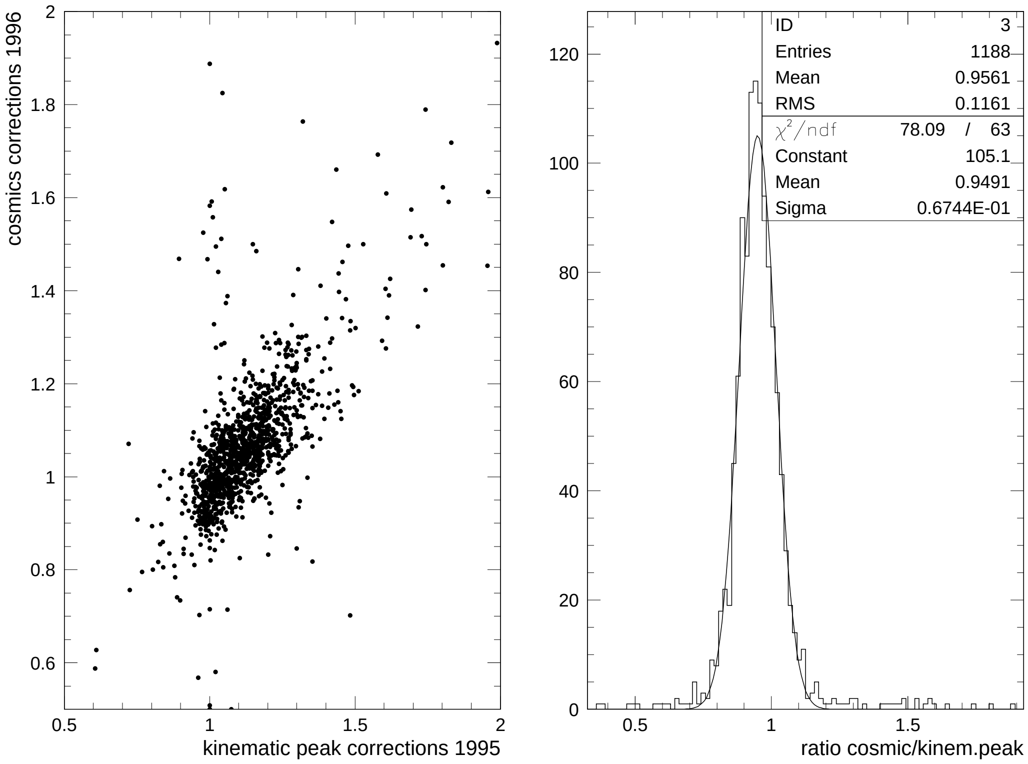

Figure 6: Correlation between the calibration constants determined by the kinematic peak (cosmic muon) analysis for the inner (outer) cells respectively in 1995 and the corrections extracted from cosmic muon data in June 1996.

3 HV setting for 1996

The procedure of HV adjustment as decribed above was proved to be an effective way to equalize the gain of the photomultipliers. In this section we briefly describe the preparation of the High Voltage settings for the data taking period of 1996.

In June 1996, before the luminosity period started, cosmic muon data were measured using the 1995 High Voltage settings. The purpose of this measurement was to find photomultipliers with changed gains. Calibration constants were extracted from the Cosmic Muon data and compared to the offline calibration constants applied in 1995. The result is shown in figure 6. In figure 6a) the offline corrections based on the 1995 kinematic peak analysis is plotted versus the corrections extracted from cosmics. Figure 6b) shows the ratio of both indicating that for the main bulk of the cells the corrections are correlated within 7% which corresponds roughly to the precision of the measurement. The entries outside the gaussian distribution correspond to newly implemented PMTs.

On the basis of this agreement new HV settings were determined and applied for cells for which the corrections from cosmics were larger than 10%.

At the beginning of the data taking period the settings were checked using kine-

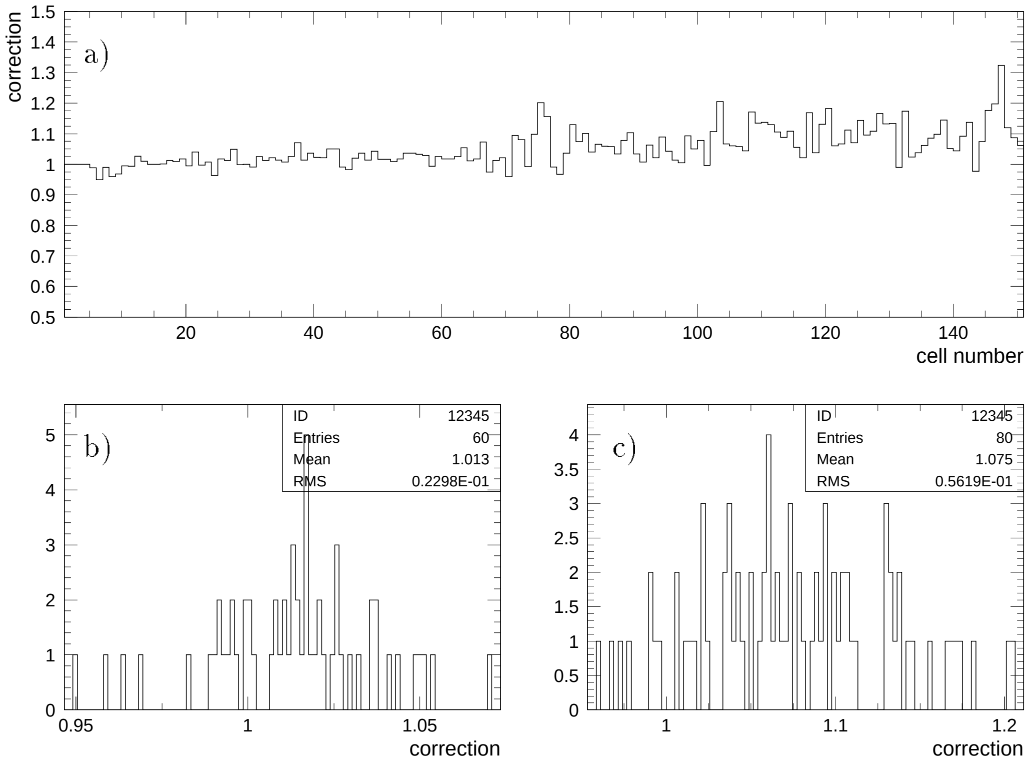

Figure 7: The level of Equalization provided by the voltage setting for 1996 is represented by correction factors shown in this figure which were determined using kinematic peak electrons. a) The correction factors are plotted vs. the cell number. b) The distibution shows the correction factors of the inner 64 cells with a spread of 2.3%. The voltage of these cells was adjusted by kinematic peak data. c) The correction factors for cell number 64 to 143 have a spread of 5%. These cells were equalized using cosmic muon data. Due to the fact that two different methods were used to adjust the gains the mean of the corrections for the inner 64 cells is lower than the mean for the outer cells by about 5%.

matic peak events. This led to the detection of one broken HV-Distribution Board (Board 27 belonging to supermodule 405[5]) which can only be fixed during an access to the electromagnetic part of the Spacal.

The final voltage for 1996 was loaded July 26 after a problem in the downloading of the reduction constants was detected and solved.

The level of equalization provided was measured by kinematic peak electrons. Figure 7a) shows a plot of the calibration constants versus the cell number for the inner 144 cells. Due to the little statistics accumulated up to now only these cells were accessible for the calibration. In Figure 7b) the correction factors of the inner 64 cells (numbers 0-63) show a spread of 2.3%. The Voltage of these cells was adjusted by kinematic peak data. Figure c) shows the correction factors for the outer cells

[5]This board contains the cells 21, 22, 23, 24, 44, 45, 46, 47, 75, 76, 77, 78, 114, 115, 116, 117.

(represented here by the numbers 64-143). They have a spread of 5% according to the systmatic error of the calibration method of cosmic muons which was used for the equalization of these cells [9]. The means of the correction factors for the inner 64 cells and for the outer cells differ by about 5%. The effect will be compensated by off-line corrections. The influence in the trigger performance is neglegible as the trigger is segmented accordingly.

No further changes of the High Voltage settings are foreseen. Note that for reasons of stability the voltages should possibly not be changed. The runranges of the different HV-settings are tabled in the Appendix.

Acknowledgments

I wish to thank Herbert Steiner who had a major part in the adjustment work in 1995 and with whom I shared many very fruitful discussions. I am grateful to Frantisek Krivan for the preparation and the service of the HV steering software and hardware and to Peter Smirnov for the construction, building and assembly of the Spacal HV System.

4 Appendix

Appendix A: HV Steering and Monitoring

Two computers `h1cal10` and `h1cal5` are used for the steering and monitoring of the voltages (see fig.1). The tasks are shared in the following way:

- `h1cal10`: The `h1cal10` is used for the steering of all Spacal electronics. It contains all steering banks (e.g. the triggers, the front-end cards, the LED-system etc.). Furthermore a data acquisition program called 'spider' is installed which is used to test the performance and to improve the adjustment and functionality of the Spacal.

  During a so-called Warmstart a downloading procedure is performed from the OS/9 `h1cal6`[6] which sets all electronics to standard values. The reduction constants of the HV Distribution Boards are described in a bank called `shvr.txt`.

  When the Central DAQ is active the Spacal-VME-Bus can not be accessed by any other system. A simultaneous access to the VME would imply the risk of a breakdown of the H1-readout-system and consequently the loss of good data. Consequently a system independent from the Central Data Acquisition is necessary for the monitoring of the voltages.

- `h1cal5`: The OS/9 `h1cal5` is used for the steering and monitoring of the calorimeter voltages. A steering and monitoring program `Spacal_hv` was developed in order to load and monitor the CAEN Power Supply. It is run on `h1cal5` on the account `hvSpacal`. The latest version of the manual for this program can be found in the instructions of the H1-shift-crew in Hall North.

[6]In 1995 it was necessary to do the Warmstart of the Spacal from `h1cal10`.

The program consists of a menu to switch the CAEN on and off and to change between three sets of CAEN-voltages called 'On', 'Reduced' and 'Expert'. The corresponding setup files are called `spacal_hv_on`, `spacal_hv_reduced` and `spacal_hv_expert`. They contain a 4-column-table with the number of the supermodule, the CAEN-board, the CAEN-channel and the voltage to be set. At the end of the file there are twelve lines for the twelve channels of the BPLUG (installed in 96) which is not equipped with a HV Distribution Board, two lines for the voltage of the radiation monitor and one line for the setting of the HV-bit.

Appendix B: HV-Alarm and Slowcontrol

The CAEN-Monitoring program continuously compares the measured voltages and currents read from the CAEN with the nominal voltages and currents. The relation between the applied voltage and the current is given by the resistance of the bases of the PMTs of about 17MΩ. As 16 cells are connected in parallel the typical current is $\sim 1800\mu$A at a voltage of 1800 Volts. If a channel shows a current of more than 2700μA for longer than 1 ms an alarmsignal is given and the voltage is switched off ('trip').

In addition the CAEN is connected to the BBL3-Slowcontrol. If a channel shows a deviation of more than 10% in the current or more than 5% in the voltage the program automatically reloads the tripped channel. One monitoring cycle takes about 3 minutes. Normally the alarm will automatically recover after this time. During the 1995 data taking it was sometimes necessary to reset the CAEN completely in order to remove the alarm because the software delivered by the CAEN manufacturer did not suppress alarms for the non-connected channels in the off-position. These channels could not be reset by the program. For 1996 a new software was implemented.

The CAEN database contains two sets of voltages V_0 and V_1. Which set is actually used depends on the status of the H1-solenoid magnet. During normal data taking the magnet is on and V_0 is used. In case the magnet is turned off the CAEN automatically switches to the set V_1 which defines much lower voltages of 1000V for all channels. This option was established in order to avoid high anode currents in the PMTs when the magnetic field is off. At a given voltage the anode currents without magnetic field are about a factor of 50 higher than at the nominal field at the Spacal of 1.0T.

At present the history of voltage operation is stored only locally in a file `SPACAL_LOGBOOK.HV`. In the future the voltage monitoring data will be stored on the oracle database [14].

Appendix C: Adjustment Software

- Off-line:

  A program to produce the High Voltage steering banks `spacal_hv_on` and `shvr.txt` in the required format was developed and is available on `dice2`.

  In order to run it the user must copy the script `/home/dice/ameyer/spacal/equi/hv.x` and specify the names of the input and output files. In the script `hv.x` detailed instructions are given.

  The starting point is a set of old voltages U_n described in the standard HV-bank format and a file of correction constants c_n. The program is based on the relation $G \propto U^6$. Hence the new voltages (U_{n+1}) are obtained from a former set of voltages (U_n) by $U_{n+1} = U_n \times c_n^{1/6}$. The program automatically reads the old banks and the correction file and produces the new banks. The user manually transfers them to the respective OS/9 stations.

- On-line:

  In order to make the adjustment of the voltages easier an Online-HV-Adjustment-Menu is planned as a tool which automatizes routine steps that were manually performed up to now. Due to its difficulty the determination of correction constants itself still has to be done offline. Following the established procedure the program applies the U^6-law. It reads the correction file from offline analysis and calculates new voltage steering banks. Using the LED-system the program monitors the gain change and displays suspicious channels (e.g. channels with HV-range-problems) to the user. The procedure is iterated in order to overcome inaccuracies of the calculation method. The flow of the procedure is planned to be as follows:

  1. Reset the system, start Spider local DAQ program, set HV and LED settings.
  2. Take LED-runs (e.g. 1000 events per run). Several runs with different settings may be necessary to accommodate all cells in the ADC range. Calculate the means $\bar{A_n}$ of all cells.
  3. Read the correction factors c_n determined off-line.
  4. Calculate new HV settings by the U^6-law and produce new HV banks. Display the change of the HV. store old banks. Give a message if hv-range-limit is reached.
  5. Download new HV settings.
  6. Take further LED runs (same settings as before) and calculate new means $\bar{A_{n+1}}$ in order to monitor the changes.
  7. Compare the ratio of the mean-values with the correction factors c_n for each cell.
  8. Calculate new corrections $(c_{n+1} = \frac{c_n}{(\bar{A_{n+1}}/\bar{A_n})})$.
  9. Iterate this procedure by continuing at step 4 until the required accuracy is reached.

  In order to establish this procedure as an online menu the `h1cal10` has to be directly or indirectly connected to the CAEN in order to set new voltages. Presently it is not connected as explained above). One possible way is a software link via ethernet. In this case the `h1cal10` would send an e-mail to `h1cal5` which in turn sets the voltages via the CAEN bus connection.

Appendix D: High Voltage Settings

Date		Run Period		HV	Method of	Relative
from	to	first run	last run	set no.	calibration	equalization
7.7.95	4.9.95	110925	120196	215	LED and Cosmics	$\sim 15\%$
6.9.95	16.10.95	120595	125403	217	Kin. Peak (Cosmics)	3%(5%)
16.10.95	24.10.95	125537	126075	218	cell 14: reduced (Hotspot)	3%(5%)
26.10.95	27.11.95	126447	131045	230	10 bad cells fixed	3%(5%)
17.6.96	1.7.96	142092	144731	232	230 (new BPLUG added)	
1.7.96	7.7.96	144732	147715	234	Calib. (downld. problem)	$\sim 20\%$
7.7.96	9.7.96	147716	148021	232	Test	
9.7.96	25.7.96	148022	151383	234	Calibration	
25.7.96	26.7.96	151385	152074	250	Kin. Peak (Cosmics)	$\sim 5\%$
26.7.96		152074		251	Kin. Peak (Cosmics)	3%(5%)

An overview over the different periods of the High Voltage Settings in 1995 is given in the table. The values the banks and log-files used in 1995 are available on dice on tape `/acs/user/ameyer/hvset95.tar.gz`. The correction-files for 1996 can be found in `/home/dice/ameyer/hvset/`.

References

[1] "Technical Proposal to upgrade the backward scattering region of the H1 Detector", H1 Collaboration, PRC 93/02 March 8, 1993

[2] T. Nicholls et al. (The Spacal Group), "Performance of an Electromagnetic Lead/Fibre Calorimeter for the H1 Detector", DESY 95-165 (1995)

[3] A description of the electronics is in preparation by the Spacal Group

[4] A. Heck et al., "Series Test of Fine Mesh Photomultiplier Tubes in Magnetic Fields of up to 1.2 Tesla", to be submitted to Nucl. Instr. and Methods

[5] V. Boudry et al. (LPNHE, Ecole Politechnique, Paris) "The inclusive Electron Trigger for the Spacal: Design and CERN-test Results", Internal Note H1 - 03/95-430 (1995)

[6] P. Verrecchia, Internal Note H1 - 09/95-456 (1995)

[7] H. Steiner, Private communication

[8] J. Janoth, J. Stiewe, A. Meyer, "An Algorithm to calibrate the new H1 Backward Calorimeter 'Spacal' using the Kinematic Peak", Internal Note H1 - 11/95-464 (1995).

[9] M. Dirkmann, "Calibration of the Spacal with Cosmics", Internal Note H1 - 05/96-477 (1996).

[10] C. Arndt, "Calibration of the Spaghetti–Calorimeter using halo muons", Diploma–thesis (german) (Dec.1995)

[11] R. Maracek, PhD Thesis (in preparation)

[12] J. Stiewe, Spacal Calibration Group Discussion (see Minutes Spacal Meeting 14.3.96)

[13] J. Janoth et al., "The LED Based Monitoring System for the New Backward Calorimeter at H1", to be submitted to Nucl. Instr. and Methods

[14] F. Lehner, Private communication.

For information about Spacal Slow events see Spacal Web Page: `http://dice2.desy.de/h1det/calo/spacal/spacal.html`