THE PERFORMANCE OF
THE H1 LIQUID ARGON CALORIMETER

MANFRED FLEISCHER
Institut für Physik
Universität Dortmund
44221 Dortmund, Germany

The H1 Liquid Argon Calorimeter has been operated successfully over a period of 7 years. During this time experience was gained in all areas of the calorimeter. In this contribution an overview will be given on the operation of the cryogenic system, the performance of the electronic system and the trigger. The achieved physics performance in terms of calibration, energy scale and resolution is discussed as well as the ongoing upgrade of preamplifier electronics.

1 Introduction

Since 1991 the H1 LAr Calorimeter has been operated in the frame of the H1 experiment at the HERA storage ring. First electron-proton collisions were recorded in summer 1992. Today HERA is operated with 27.5 GeV positrons and 820 GeV protons. The time interval between bunch crossings is 96 ns, setting the scale for appropriate timing of trigger and analog electronics.

The LAr Calorimeter [1] is one of the main components of the H1 detector, which is described elsewhere [2,3]. It consists of an electromagnetic and hadronic section. The electromagnetic section is built as a stack of absorber boards with a lead kernel of 2.4 mm and argon gaps of 2.35 mm. It consists of 30784 cells having a transverse cell size of 10 – 100 cm^2. The depth varies between 20 and 30 X_0. The hadronic section is built out of 19 mm thick stainless steel absorber material intercepted by a double argon gap of 2 $\times$ 2.4 mm. The number of hadronic cells amounts to 13568 with a transverse size of 50 – 2000 cm^2. The total depth (including the electromagnetic section) amounts to 4.5 λ in the central region and up to 8 λ in the forward region.

The H1 LAr Calorimeter, shown in Fig. 1, is structured into 8 self supporting wheels, each section in BBE, CB and FB is divided into 8 octants or in case of IF and OF into 2 half shells. The absorber structure together with the LAr volume of 53 m^3 has a weight of about 600 tons.

2 Operating the H1 LAr Calorimeter

The LAr Calorimeter is operated using various steering, monitoring and acquisition subsystems which are briefly described below.

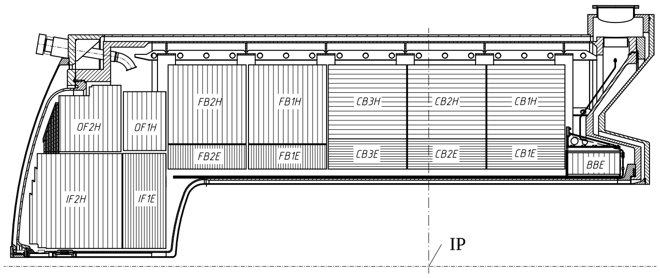

Figure 1: Cross section of the H1 LAr Calorimeter

2.1 The Cryogenic System

The cryogenic system is steered by a set of VME based OS9 systems. All relevant data, like measured pressures, temperatures, levels, as well as the status of various components, like valve positions, are monitored by a PC based system and are stored locally every 30 seconds. On the basis of the cryogenic data sets the most relevant temperatures, pressures and levels are averaged over an interval of one hour and stored in an Oracle database. This allows an easy access via WWW based software tools to the cryogenic data, enabling controls from off-site and systematic studies.

The cryostat has been in stable operation since 1991, without any warm up since it was filled. The pressure is kept at 1.28 bar and the temperature at about 88.8 K. Only minor variations are seen during luminosity periods, mostly correlated to refills of the LN_2-tank or due to rare and short time failures of essential components like the inter-cooler, positioned half way between the LN_2-tank and the cryostat.

2.2 LAr Purity Monitoring

In order to monitor the LAr purity three methods are employed, which are used on different time scales.

One method uses 11 small ionisation chambers positioned at various locations in the cryostat which are equipped with either α or β sources. The energy spectra of these probes are measured continuously (every 2 hours) with a constant HV setting. The data are recorded on a PC and stored in an Oracle data base. The development of the signal height, corrected for variations of the LAr temperature, is shown in figure 2.

These regular measurements are cross checked using another operation mode of the probes, where the amplitude is measured as a function of the

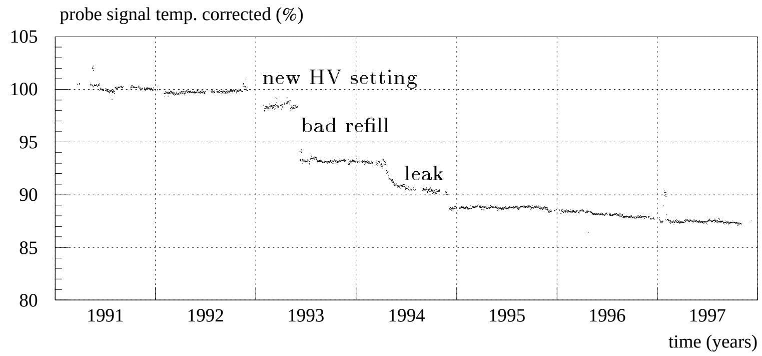

Figure 2: Development of the LAr purity since 1991

HV applied to the probes. The HV/amplitude dependence is fitted using (in approximation) a parameterization for point-like charges, and yields the charge collection at an infinite electrical field as well as the impurity. These measurements are performed once every few months.

The third method – independent of the probes – uses muon data, which are recorded at 6 different HV settings. The calorimetric data, taken without zero suppression, are first corrected for the precise pedestal position using noise events. On the basis of tracking information a cylinder around the muon track is optimized such that the maximum charge is collected inside. The calorimeter response is fitted using track like parameterizations. These investigations are typically done once a year.

Over the 7 years of operation about 13 % of the β probe signal height has been lost (figure 2) due to an increase of impurity, which presently amounts to about 1.3 ppm. Apart from a leak in 1994, a significant increase of impurity was due to a bad refill of the cryostat after a movement of the detector to the shut-down position. In order to avoid further significant purity losses the shut-down related movements of the detector are performed without emptying the cryostat since the begin of 1995. In autumn 1997 the charge collection efficiency was determined to be 0.85 ± 0.02 at nominal voltage of 1500 V using the second method described above. The other two methods lead to consistent results within their systematic errors.

2.3 The HV system

The approximately 8000 gaps of the H1 LAr Calorimeter are supplied by 1504 individual HV lines. In order to avoid inactive calorimeter cells due to problems with an individual HV line, each cell is supplied by several, ≤ 12 HV lines.

The HV is generated by 56 CAEN HV generators each feeding a distributor with 32 output channels. For each HV line the current is monitored by an OS9 system via a VME-bus interface. The thresholds for an overcurrent are set to 2 μA in the central barrel and 6 μA in the region of the inner forward calorimeter modules (with respect to the proton direction). HV lines with currents exceeding these thresholds are either connected to distributor crates that can supply up to 200 μA for all connected channels, or/and are operated at a lower voltage of only 1000 V. About 96.3% of all HV lines are operated at nominal voltage of 1500 V, chosen for stability reasons, corresponding to an electrical field of 625 V/mm. Only 3.5% of all HV lines are on reduced voltage, 0.2% are grounded.

Each HV channel is monitored continuously and significant changes of voltages or currents are recorded. On the basis of this information correction factors are determined which are applied during the offline reconstruction. These HV correction factors for the individual calorimeter cells are typically small, on average about 2%. The HV corrections [4] lead to a significant improvement of energy scale and energy resolution.

During luminosity runs the HV system behaves very stably, especially since 1995 when any emptying/refilling of the cryostat has been avoided during shutdowns. Instabilities of the HV supply are only due to bad beam conditions, e.g. overcurrents during periods of unsuccessful proton injections.

3 Calorimeter Electronics

The 44352 cells of the H1 LAr Calorimeter are read out via ganging cables connected to the readout boards located in the cell gaps. About 3000 signal cables are fed through the cryostat walls using special feedthroughs, nearby the "analog boxes", in which the preamplifier electronics are located. Here the signals are amplified and split into the energy readout and the trigger path.

In order to monitor and to calibrate the calorimeter electronics, signals from 992 electronic pulsers are fed in both close to the cells in the cold area ("cold calibration") and close to the preamplifier outside the cryostat ("warm calibration").

3.1 Analog Electronics and Readout

Since the average cell capacity is 5 nF ($1 \leq C_d \leq 18$ nF) the amplified signals are shaped using a shaping time of 2.4 μs in order to optimize the signal to noise ratio. The noise charge of the entire electronic chain is $Q_{noise} = 5000 e_0 C_d + 5500 e_0$ (C_d in nF).

In most regions of the calorimeter the noise depends only on the cell size and the white noise limit is reached, after various noise sources have been traced and eliminated. The measured noise varies between 0.25 mips in the electromagnetic section of the central barrel region to 0.15 mips elsewhere. Over a year of operation only minor fluctuations of the individual channel noise levels are seen, typically less than 4%.

In order to cover a big dynamic range with sufficient precision using 12 bit ADCs the signals of about 16000 selected cells are amplified with two different gains. So the electronic systems of the energy readout branch consists out of 60470 electronic channels in total.

Due to the location outside the cryostat the preamplifier/shaper electronics can be accessed easily, so that repairs can be undertaken even during short 1-day shut-downs. This feature manifests in very good channel statistics: from 60470 electronic channels only 111 channels were problematic in 97 (0.2%), where 19 were dead already since the cryostat was closed in 1991 and 67 channels are susceptible to magnetic field due to neon bulbs involved.

After a twofold multiplexing the analog signals are sent via twisted pair cables to analog receiving units, are digitized in 12 bit ADCs and are processed by fast digital signal processors. Here a pedestal subtraction and an essential data reduction is performed. All signals that pass the 2 – 3 σ_{noise}-cut are corrected using a third order polynomial on the basis of electronic calibration data.

The calorimeter readout takes about 1.1 ms applying standard zero suppression cuts. For normal luminosity conditions, the calorimeter readout is operated at a typical rate of less than 50 Hz, the maximum rate is 250 Hz for the calorimeter readout. The event size is typically below 10 kByte, for an average of about 1200 kept channels. In case of de-activated zero suppression the event size reaches 200 kBytes.

3.2 The LAr Trigger

Already on the preamplifier boards the signals of the 44352 calorimeter cells are grouped and summed into 5009 trigger cells. The shaped signals (0.5 μs shaping time) of up to 4 electromagnetic resp. up to 6 hadronic trigger cells are combined to 656 trigger towers. These trigger towers are further grouped into 256 big towers. The signals of the big towers, built from signals of trigger towers exceeding noise dependent thresholds of the order of 1 GeV, are digitized in FADCs. In figure 3 the nice correlation between the measurement in the trigger FADCs and the final reconstructed energy is shown [5]. 1 FADC count translates to 125 MeV.

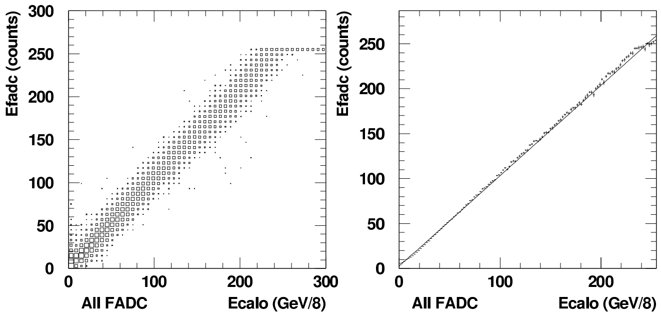

Figure 3: Correlation between the reconstructed energy and the energy determined by the trigger. In the right plot the points indicate the mean and the error bars the sigma. The straight line corresponds to the nominal gain.

Beyond the above mentioned trigger sums other objects like e.g. transverse energy, missing energy, electron energy can be combined on the basis of the electromagnetic and hadronic big towers. Here dedicated weighting algorithms and various thresholds are implemented.

All trigger decisions of the LAr trigger system are supplied within 2.1 μs to the H1 central trigger system ruling the readout of the entire H1 detector.

4 Checks for the Energy Calibration

Before starting the operation of the H1 LAr Calorimeter several test beam measurements were performed, see [1,6,7,8] for obtained results. The linearity was proven to be better than 1% up to 166 GeV. The energy resolution for electrons was found to be 12% / $\sqrt{E_e(GeV)} \oplus 1\%$. In case of pions an energy resolution of 50% / $\sqrt{E_h(GeV)} \oplus 2\%$ was obtained.

During the first 3 years of HERA/H1 operation 92–94, an integrated luminosity of about 4 pb^{-1} of good quality data was accumulated. Using deep inelastic ep data (see figure 4) the precision of the electromagnetic energy scale was verified to be 3% and the precision of the hadronic energy scale was proven to be 4%. These numbers were cross checked using wide angle bremsstrahlung events (QED-Compton scattering: $ep \to ep\gamma$, where the proton escapes unscathed in the proton beam direction) as well as cosmic muon events where low energetic electrons were radiated, which allow a cross calibration of tracking and calorimeter in the low energy domain.

During the years 95–97 the delivered integrated luminosity increased significantly. In these 3 years H1 collected ten times more luminosity than in the years 92–94.

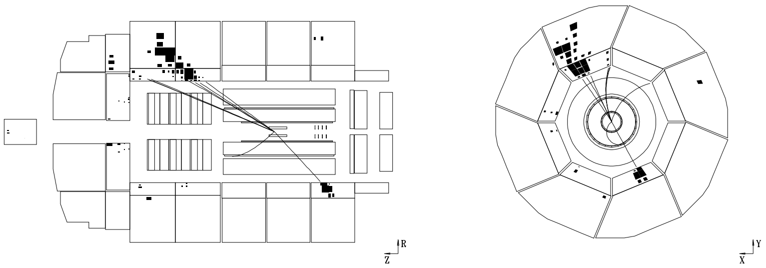

Figure 4: DIS event with large momentum transfer measured with the H1 detector in transverse and radial view. The scattered electron is detected in the CB and is balanced in p_t by the hadronic final state.

In case of deep inelastic ep events with large momentum transfer the outgoing electron is scattered into the LAr Calorimeter, as displayed in figure 4. The high energetic scattered electron with an energy of typically more than 20 GeV is balanced in p_t by the hadronic final state. By using just the angles (with respect to the incident proton) of both the electron (θ_e) and the hadron jet (γ), the energy of the electron can be calculated by using the double angle method [9] according to the following formalism:

$$E_{DA} = \frac{2\ \sin\gamma}{\sin\gamma + \sin\theta_e - \sin(\gamma + \theta_e)} \quad E_{e,beam}$$

The calculated energy E_{DA} can be used to correct the measured energy. The results of such study are shown in figure 5, where the binning was chosen according to the impact point of the electron in the calorimeter. With increasing z (ie. towards the backscattered electron) the available statistics dies out due to the lower cross section in that kinematic domain.

After performing corrections to the electromagnetic energy scale, the transverse momentum of the electron was compared to the that of the hadronic final state. The ratio is shown for both data and Monte Carlo in figure 6. Data and Monte Carlo are in good agreement, demonstrating the quality of weighting techniques [10] which are applied for the reconstruction of hadrons due to the non-compensating calorimeter setup.

5 The Preamplifier Upgrade

In order to substantially reduce the noise in the calorimeter electronics an upgrade of the front end electronics was proposed recently [11]. During the winter shut-down 97/98 those channels with large capacities ($C_d > 5$ nF) will be equipped with new preamplifiers based on low noise JFETs NJ3600 (built

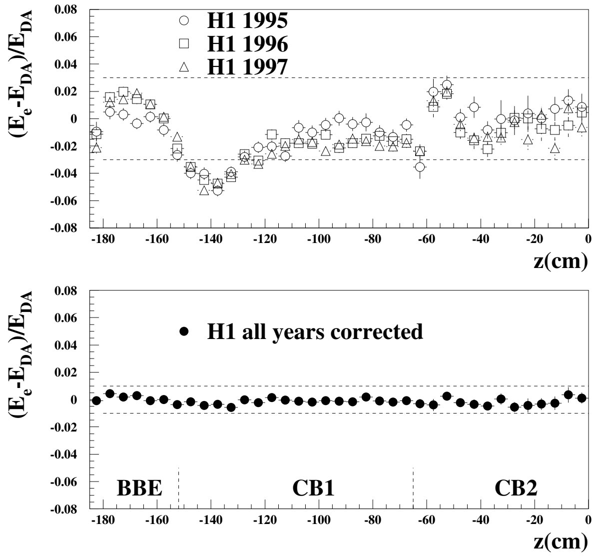

Figure 5: Results of a preliminary H1 study of the calorimeter energy scale: shown is the ratio $(E_e - E_{DA})/E_{DA}$, where E_e denotes the measured electron energy and E_{DA} is the calculated energy. The analysis is restricted due to the central and backward region of the H1 LAr Calorimeter (BBE, CB1 and CB2) and based on data taken in the last 3 years. In the upper plot the uncorrected data are shown, where fluctuations near to crack regions are visible. The behaviour of the three data samples of the years 95, 96 and 97 is stable and consistent within the statistical errors. In the lower plot the ratio is shown after correcting the measured electron energy with a set of z-dependent correction factors common for all years involved. A band of $\pm$ 1% is drawn around the expectation.

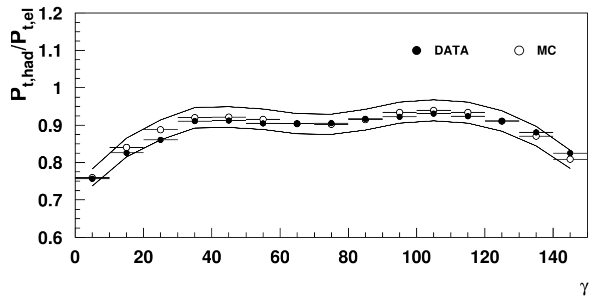

Figure 6: Results of a preliminary H1 study: shown is the ratio of hadronic transverse momentum $p_{t,had}$ to the electron transverse momentum $p_{t,e}$ versus the angle of the hadronic final state γ for both, data (closed) and Monte Carlo (open symbols). For the calorimeter only, as shown here, the ratio does not reach one due to energy and particle losses in the tracking region in front of the calorimeter. In the forward region (small γ) and in the backward region (large γ) the ratio decreases for acceptance reasons. A band of $\pm$ 3 % is drawn around the Monte Carlo expectation.

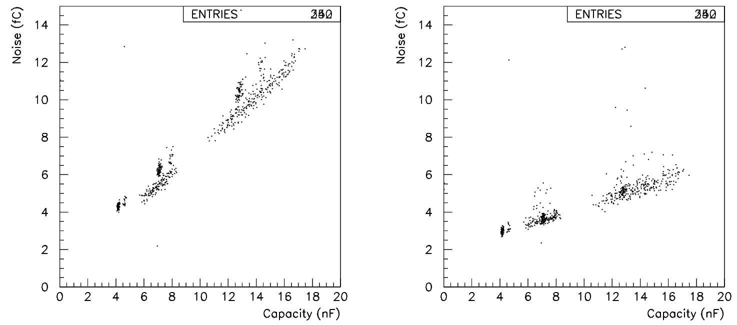

Figure 7: Noise measurements before (right) and after (left) upgrade of new preamplifiers and removal of resistors as function of the cell capacity. Even after the upgrade the noise is governed mainly by the capacity, demonstrating that the white noise limit is reached in both regions BBE and CB1E.

by Interfet corporation). Due to the larger transconductance of the JFET NJ3600 ($g_m \approx 200$ mSi) compared to the presently used one (Toshiba SK 372, 60 mSi) a noise reduction factor of up to 1.8 is expected, depending on the detector capacities.

The upgrade of the preamplifiers is accompanied by a modification of the trigger electronics which allows in future to handle thresholds for electromagnetic and hadronic trigger towers separately. This allows to lower the thresholds in the hadronic section significantly due to the small capacities involved there.

To achieve a further reduction of the noise, the series resistor in front of the preamplifier will either be removed or exchanged, which was originally meant to serve as protection against damage from sparking. It turned out, that this protection is not needed due to the presence of a high resistive coating of the HV planes and the passive impedance of the signal cables.

The performance of these new preamplifiers has been successfully tested in situ by instrumenting two regions in CB1 and BBE (4 complete big towers). Two noise measurements of the channels concerned are shown in figure 7 for both regions of instrumentation, CB1 and BBE, before and after instrumentation of preamplifiers together with the removal of resistors.

The upgrade will lead to a substantial reduction of noise in both the energy readout branch and the trigger branch. So on one side the effective trigger thresholds can be lowered significantly while maintaining an acceptable rate. Several physics channels – such as $J/\psi \to e^+e^-$, $J/\psi \to \mu^+\mu^-$ or charged current events ($ep \to \nu_e X$) – have been investigated and significant improvements of the efficiencies are expected. On the other side the low noise leads to a better energy resolution in the low energy domain and a better sensitivity for low energetic particles depositing only small energies close to the noise level. Such particles constitute a considerable fraction of the signal induced by hadronic jets.

Later, in the age of the HERA luminosity upgrade [12], foreseen for the year 2000, the trigger can be operated in a safe way using current threshold settings. The rate at the trigger tower is expected to be, despite the increase of luminosity, very stable and about 1–3 orders of magnitude lower than that of today without any loss of physics in the kinematic domain of high momentum transfers.

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References

1. H1 Calorimeter Group, B. Andrieu et al., NIM A336 (1993) 460-498.
2. H1 Collaboration, I. Abt et al., NIM A386 (1997) 310-347.
3. H1 Collaboration, I. Abt et al., NIM A386 (1997) 348-396.
4. J. Spiekermann, HV Correction for the H1 LAr Calorimeter, Internal note H1-01/95-422, January 95.
5. T. Carli et al., Performance of the LAr Trigger in 1994, contribution to Int. Europhys. Conf. on HEP, eps0644, Brussels, July 1995.
6. H1 Calorimeter Group, B. Andrieu et al., NIM A336 (1993) 499-509.
7. H1 Calorimeter Group, B. Andrieu et al., NIM A344 (1994) 492-506.
8. H1 Calorimeter Group, B. Andrieu et al., NIM A350 (1994) 57-72.
9. S. Bentvelsen et al. and K.C. Hoeger, in Proceedings of the Workshop Physics at HERA, ed. W. Buchmüller and G. Ingelman, DESY 1992.
10. H.P. Wellisch et al., Hadronic Calibration of the H1 LAr Calorimeter using Software Weighting Techniques, MPI-PhE/94-03, January 1994.
11. A. Babaev et al., Proposal to Upgrade the LAr Calorimeter and Trigger Electronics, DESY PRC 96/03.
12. H1 Collaboration, *ep*-Physics beyond 1999, Internal note H1-10/97-531, October 97.