H1–01/96–470
PRC – 96/03

Proposal to Upgrade the LAr Calorimeter and Trigger Electronics

A. Babaev, K. Borras, H. Brettel, T. Carli, B. Dulny, J. Fent, M. Fleischer, C. Kiesling, J. H. Köhne, D. Lüke, W. Pimpl, H. Rick, K. Rüter, J. Spiekermann, K. Wacker, D. Wegener, A. Wegner, P. Weißbach

Max-Planck-Institut für Physik, München, Germany
Institut für Physik, Universität Dortmund, Dortmund, Germany

Abstract

White noise is presently limiting the thresholds for the liquid argon (LAr) calorimeter trigger. In order to be able to further reduce the trigger thresholds and therefore to become more efficient in the coming years for ep reactions with low energy deposit in the calorimeter, and to ensure the present trigger thresholds in future high luminosity running, we propose an upgrade program for the analog calorimeter electronics. The proposal consists of two parts:

First, we want to equip the barrel region of the LAr calorimeter with new low-noise preamplifiers to reduce the white noise by a substantial amount. The gain in noise reduction is about a factor of 1.8 in the electromagnetic and about 1.4 in the hadronic sections of the barrel. We would like to stress that the proposed upgrade not only improves the noise in the trigger but also, by the same amount, the noise level in the calorimeter. As a consequence, we expect to improve the sensitivity for low energy particles.

The second part foresees to provide the same reduction of noise as above also on the trigger level by increasing the granularity of the trigger towers. This is achieved by separating the electromagnetic and hadronic parts of a tower and by discriminating them individually. This change envisages a re-design of the signal gating in the analog part of the LAr trigger electronics.

Besides the obvious benefits for the first level liquid argon trigger, the low noise situation in the calorimeter would also largely support the efficient operation of the level 2 trigger systems.

1 Introduction

Since the startup of H1 at HERA, the thresholds for triggering the LAr calorimeter have been decreased in a series of significant steps. The reasons for the lowering were the detection and removal of noise sources outside of the trigger system. A detailed analysis [1] of the data from the 1994 running period shows that the thresholds have now reached their theoretical lower limit, determined by the white noise in the preamplifier electronics. For a typical medium capacity trigger tower the threshold is set to about 1 GeV, which corresponds to cutting the noise at the 3 σ level.

A number of physics channels exist which would substantially profit from even lower thresholds. Examples are the exclusive and inclusive production of J/ψ particles, open charm production and low p_T jets from untagged photo-production. The required thresholds are about a factor of 2 lower than the ones obtainable with the present electronics.

Any further lowering of the thresholds can only be achieved by cutting the noise at its root. From a circuit analysis, substantiated by measurement in situ, it became evident that the dominant noise contribution comes from the first transistor in the amplification chain for the LAr signal. With presently available custom-designed JFETs as the first transistor, a noise reduction of about a factor of two for the large detector capacities seems in reach. This noise reduction would not only help the trigger but also be beneficial to the energy resolution of the LAr calorimeter itself.

We first present the analysis and status of the noise in the calorimeter and the trigger, then describe the planned improvements (low noise preamplifiers and analog gating modules). We give first results from beam tests in H1 of the proposed solution and present selected physics topics showing the gain in sensitivity of the upgrade program, which is planned to be realized in two steps. Finally we present a time table and the costs for the upgrade program, giving details of the staging scenario, including the financing for the first part of the proposed upgrade.

2 Amplification and Noise

Detectors based on ionisation measurement, as e.g. the LAr calorimeter of the H1 detector measuring the energy depositions of particles, represent a capacitive source of charge to the amplifier electronics. In such electronics, noise is generally added to the signal and deteriorates the energy resolution determined by the statistics of the particle energy loss. We will shortly discuss here this unavoidable source of electronic noise and present measurements quantifying the noise. Of course, any external noise source has to be eliminated before the limits of measurement accuracy due to electronic noise in the detector and the charge amplifier can be approached. We will show in the following that the noise in the trigger electronics is well understood and coincides with the expected amount from the capacitive load of the calorimeter cells forming them. At present, this noise is the limiting factor for setting the thresholds.

2.1 Theoretical Analysis

Basically, the noise process in amplifier electronics can be viewed as a sequence of randomly generated impulses which have a Poissonian distribution in time. Such a random sequence arises, e.g., from charge carrier generation in the circuitry of the amplification electronics, in which the carriers have, e.g., to cross a potential barrier (work function) leading to a thermal (Boltzmann) distribution of energies. To be more specific, let us consider a typical junction field-effect transistor (JFET) used in the first amplification stage of the calorimeter electronics. In such a device the drain current I_D which constitutes the amplified signal, depends on the potential V_G at the gate being produced by the charge Q_s collected from the sensing electrode, i.e. the signal. The gain g of the amplifier is given by

$$g = \frac{g_m}{C_G},$$

where g_m is the transconductance, defined as

$$g_m = \frac{dI_D}{dV_G}$$

and C_G is the capacitance between gate and source of the JFET. The intrinsic thermal noise in the conducting channel of the JFET adds to the drain current I_D. Its variance is proportional to the transconductance (for more details see [2]) and is given by

$$\sigma^2_{I_D} = 4kTa_n g_m,$$

where T is the temperature and a_n is a 'technology' factor ($a \approx 2/3$ for JFET's and $\approx 1/2$ for bipolar transistors). This fluctuation of drain current can be viewed as an equivalent fluctuation of the gate potential V_G:

$$\sigma^2_{V_G} = \frac{\sigma^2_{I_D}}{g_m^2} = 4kT\frac{a_n}{g_m}$$

Since the gate potential is generated by the signal charge, the variance of this potential can also be expressed in terms of the charge induced on the sensing electrodes, leading to the concept of an 'equivalent noise charge (ENC)':

$$\sigma^2_{Q_G} = 4kTa_n\frac{{C_G}^2}{g_m}.$$

Now the charge Q_G at the gate can be translated to an equivalent charge at the sensing electrode Q_s

$$Q_s = Q_G\frac{C_G}{C_D + C_G},$$

where C_D is the capacitance of the sensing electrode (to ground). This finally leads to the fluctuation $\sigma^2_{Q_s}$ of the signal charge on the sensing electrode:

$$\sigma^2_{Q_s} = 4kTa_n\frac{(C_D + C_G)^2}{g_m}, \tag{1}$$

or, more formally, to

$$\sigma(\text{noise}) = a + bC_D \tag{2}$$

with

$$a = \sqrt{\frac{4kT}{g_m}}C_G \quad \text{and} \quad b = \sqrt{\frac{4kT}{g_m}}$$

It should be kept in mind that the above expression for the noise is a simplification in several ways: First of all, only the 'serial' noise [2] is taken into account. This approximation is justified for most of the detector capacities in the LAr calorimeter channels. Only at the very low capacity end (even much below the capacities in the LAr calorimeter) do we expect noticeable contributions from 'parallel' noise. Secondly, the noise contribution σ_{Q_s} is frequency-dependent due to the filtering process of the amplifier electronics, which is not taken into account in our simplifying discussion. Again, only the low capacities will be affected and we therefore neglect the frequency dependence. Finally, we assume that the noise distribution is a pure Gaussian. In our discussion of the noise we will use a model based on all these simplifications ("white noise" model).

Within this model the noise transmitted to the readout channels of the calorimeter (and to the trigger), is proportional to the capacity of the calorimeter cell seen by the electronics (see eqn. 2). A measurement of the equivalent noise in units of electrons, obtained in the LAr calorimeter, confirms the preceding theoretical analysis, yielding the following relation [3]:

$$\mathrm{ENC}_{\mathrm{Calo}} = 3500 + 4600 C_{\mathrm{D}},$$

where C_{D} is the calorimeter cell capacity in nF. Clearly, the large capacities in the calorimeter contribute most to the noise.

Provided one keeps the detector granularity unchanged, the basic parameters to optimize for low noise are the temperature T and the transconductance g_m. While lowering the temperature seems in principle straightforward, a substantial reduction in noise is achieved only at cryogenic temperatures. We skip this possibility and concentrate in our upgrade proposal on the "technological" factor g_m.

2.2 Noise in the trigger channel

Using our simplified model and the above relation the expected noise in the trigger towers can be estimated. The only modification to be applied is the unavoidable increase of noise due to the shorter time constant in the trigger shaper:

$$\mathrm{ENC}_{\mathrm{Trig}} = \mathrm{ENC}_{\mathrm{Calo}} \sqrt{\frac{\tau_{\mathrm{Calo}}}{\tau_{\mathrm{Trig}}}}$$

This expression gives the contribution to the trigger noise from a single calorimeter cell of capacity C_{D}. For a full estimate of the noise in a given trigger cell or trigger tower, the individual calorimeter cell noise contributions have to be added in quadrature.

In Fig. 1 a) and c) the correlation between the measured noise and the prediction of the simple white noise model is shown. The validity of the white noise model is nicely demonstrated by the observed correlation. It can be read from Fig. 1 d), illustrating the correlation between the noise measured by the trigger and the calorimeter readout branch, that the noise in the trigger channel is dominated by the noise produced in the calorimeter itself. No significant additional noise is introduced by the trigger electronics. There are, however, certain regions in the calorimeter with larger noise than expected. The origin of this noise is not clear at present, but it is as well seen in the calorimeter. A possible hypothesis for the additional noise in the calorimeter is pickup. This noise contribution is, however, not the limiting factor for triggering.

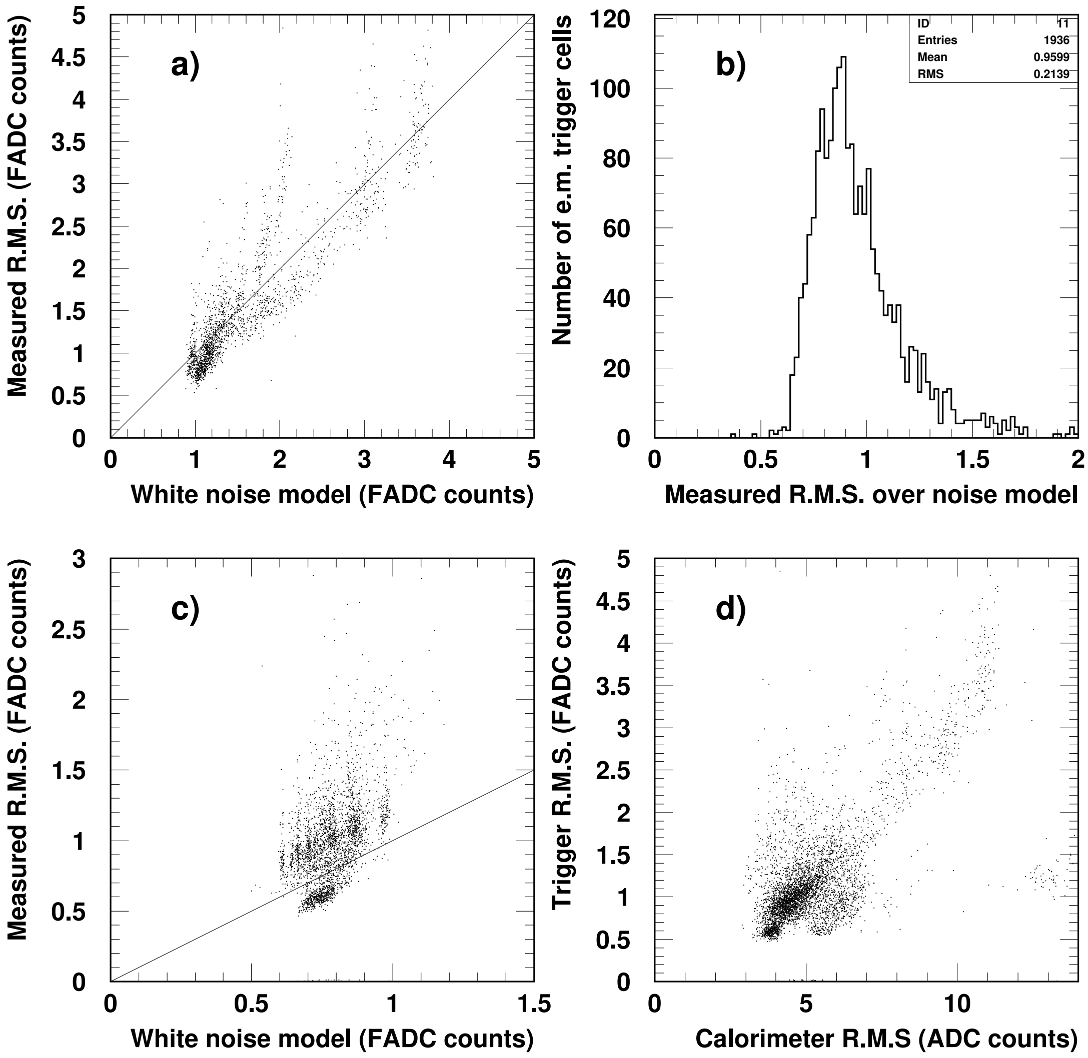

Figure 1: *Correlation between the root mean square (R.M.S.) of the noise distribution observed at the trigger level and the prediction from a simple white noise model (mainly based on the capacity of the trigger cells) for electromagnetic (a) and hadronic (c) trigger cells. The ratio of the observed R.M.S. over the prediction from the white noise model is shown in b). The correlation between the R.M.S. as measured by the trigger and the calorimeter readout branch is shown in d).*

3 Noise Reduction at the Preamplifier Stage

The preamplification stage of the LAr electronics is realized in the so-called analog card (ANCD) housing 16 calorimeter channels. The ANCD's are located in the analog boxes (ANBX) which are mounted onto the cryostat. On the ANCD the individual signals are stored in a sample/hold circuit for later read-out via a special multiplexer hybrid. Furthermore the 16 calorimeter channels are summed in a separate trigger channel for immediate transmission to the LAr trigger electronics, situated in the electronic trailer.

Each of the basic circuit elements on the ANCD (preamplifier, summing amplifier, sample/hold and multiplexer) are realized in a hybrid technique. The preamplifier hybrid and the motherboard have been designed and manufactured by MPI Munich, the analog cards have been manufactured in industry and were tested at MPI. For the LAr calorimeter a total number of about 2500 ANCD's are installed.

As a result of the analysis above, the noise in the LAr signal chain is dominated by the first transistor of the preamplifier circuit. When this circuit was designed in 1984, the most suitable transistor for the time constants involved was the JFET 2 SK 372 by Toshiba [4]. However, the large range of capacities in the system (from 1 to 18 nF) made it difficult to optimize the circuit design. Ten years later, a new JFET NJ3600 by InterFet Corporation [5] has become available, which is especially designed for large capacities. The main characteristics of the InterFET NJ3600 is its high transconductance g_m = 200 mSi, as opposed to 60 mSi from the Toshiba JFET. A consequence of this gain is, however, a substantially higher drain current (20 mA at 12 Volts as opposed to 5 mA) and higher power consumption of the chip. Assuming the same figure-of-merit (g_m/C_G), a rough guess of the expected noise reduction factor (see eqn. (1)) is about 1.8. With the NJ3600 JFET it is possible to design a new preamplifier hybrid and exchange the new hybrid with the old one on the motherboard. By this procedure we can offer a low-cost solution, well suited for series production.

At the MPI we have designed and built a new preamplifier hybrid around the NJ3600, which would replace the old one on the ANCD. The schematics of this hybrid is shown in Fig. 2. The design goals were to preserve the gain of the amplifier and at the same time reduce the noise. The actual reduction depends on the detector capacity and the unavoidable noise of the other preamplifier components on the hybrid. We have measured on the new hybrid with the NJ3600, at 10 nF, a noise reduction of a factor of 1.6. In order to further reduce the noise we propose to exclude the serial resistor R_s from the design, which was meant to serve as protection against damage from sparking. We believe (and have in fact tested in the actual H1 calorimeter, see below) that the protection is not needed for the electromagnetic channels, which are already protected by the high-resistive coating of the high voltage planes and the passive impedance of the cables from the detector to the analog boxes.

With this additional noise source removed, an overall gain of a factor of 1.8 (at 10-12 nF) is expected from detailed simulations of the hybrid. Measurements of analog cards equipped with the new hybrids show that the expected gain is fully achieved. Examples of measurements of some upgraded analog cards, compared to old ones, is shown in Fig. 3. In the capacity range from 5 nF to 18 nF (most of the

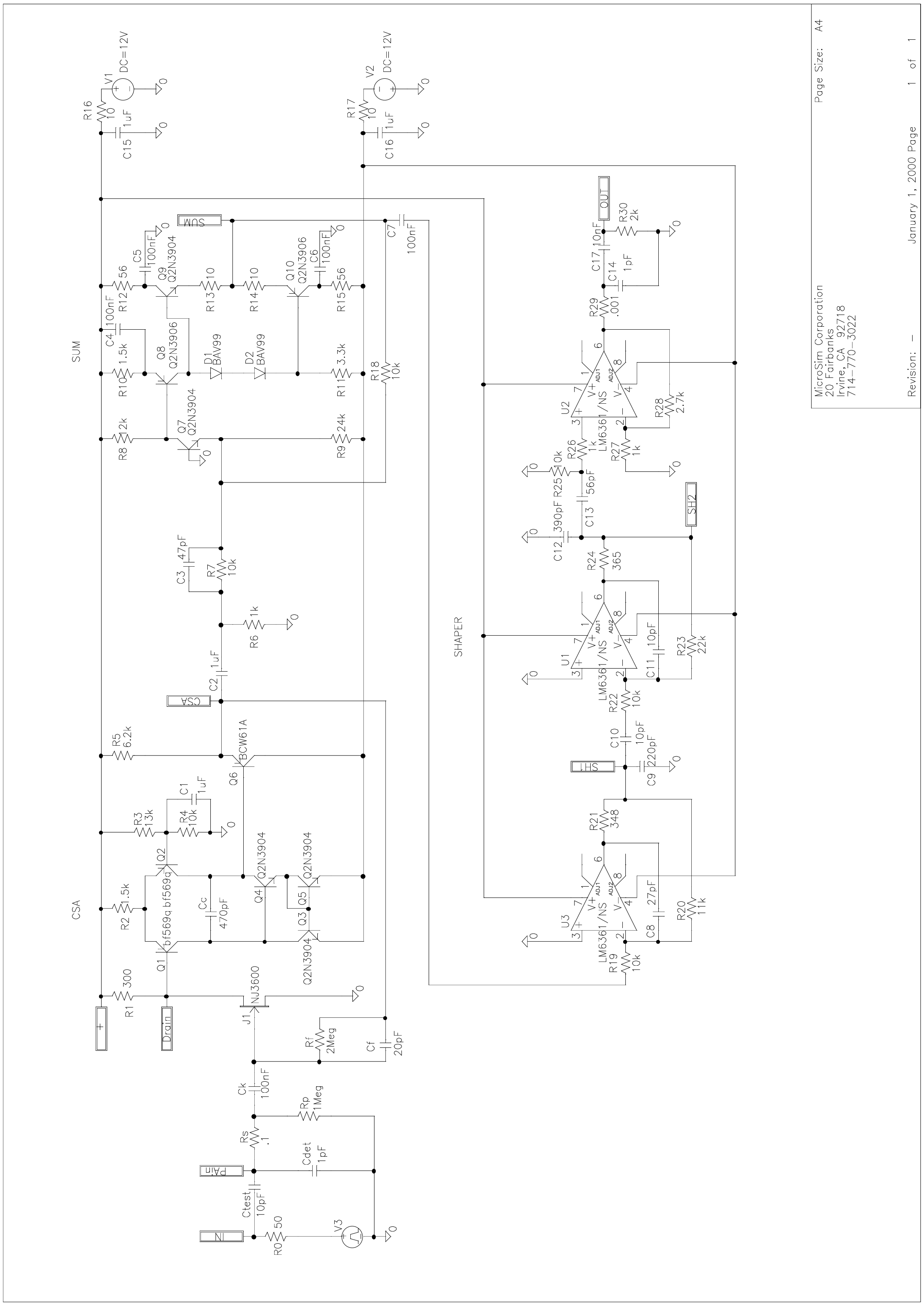

Figure 2: *Schematics of the preamplifier hybrid, designed around the NJ3600 JFET. The other circuit element indicated is series resistor (Rs,.1), which is inserted to protect the circuit against high voltage break-down (sparking).*

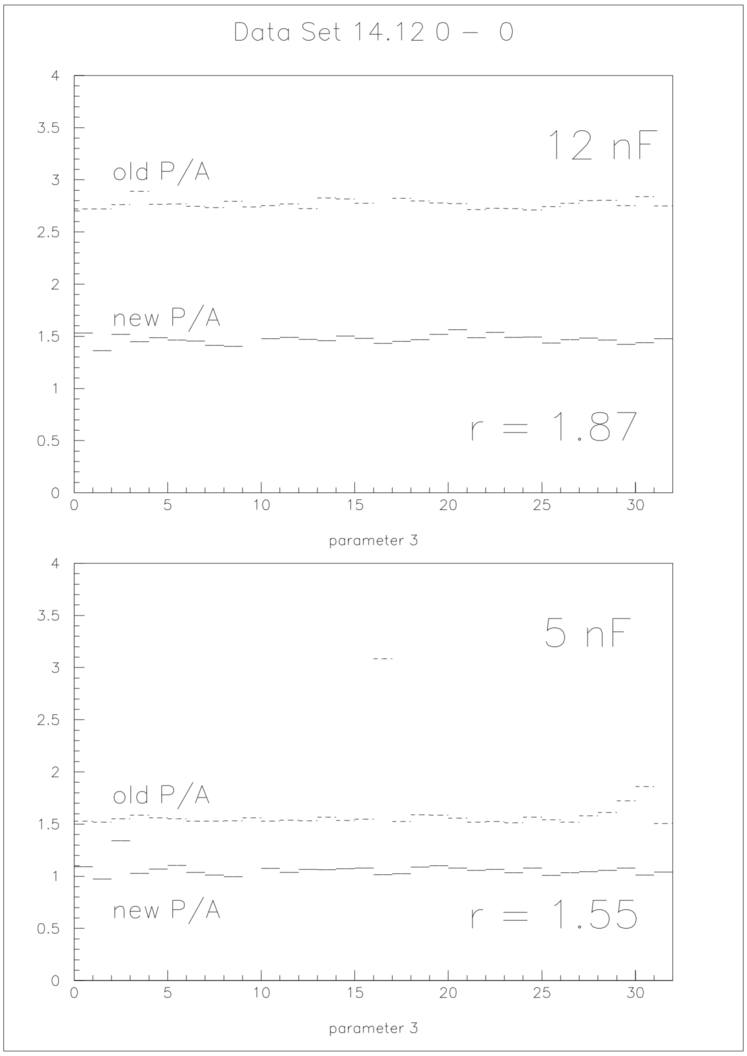

Figure 3: *Comparison of noise levels for two randomly chosen analog cards with a total of 32 preamplifiers equipped with the new and the old hybrids. The horizontal axis is the channel number (parameter 3, each bin corresponds to a specific preamplifier), the vertical axis gives the measured noise (σ of a Gaussian fit to the noise spectra) in ADC counts. Measurements are taken at two different values of the detector capacity as indicated.*

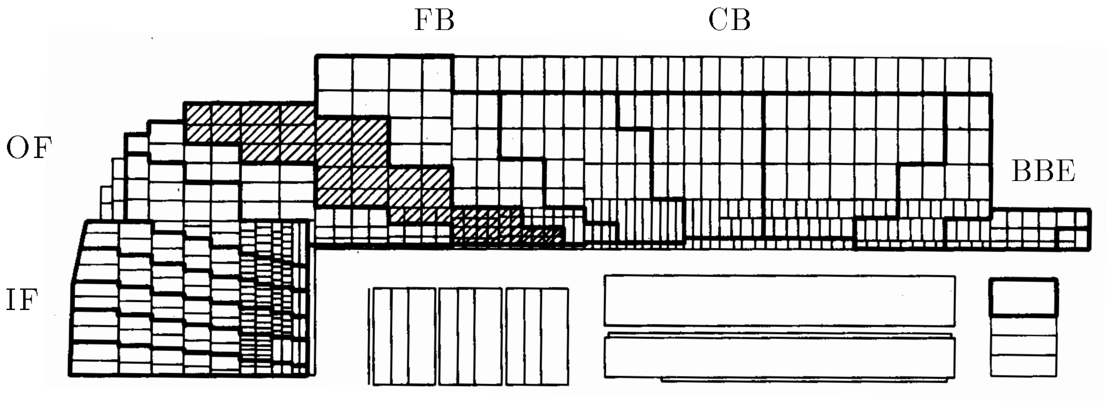

Figure 4: *Cross section through half of the liquid argon calorimeter, showing the wheel and calorimeter cell structure. The shaded area marks one of the 252 big towers, from which the trigger quantities are derived.*

channels in the electromagnetic part of the barrel are in this range) we expect, on the basis of these measurements, noise reductions between 1.5 and 2.2.

4 Beam Tests

At the end of October 1995 a total of 816 channels (in 51 analog cards) were equipped with the new preamplifiers. A schematic view of the calorimeter showing its wheel and cell structure is depicted in Fig. 4. The cards were installed in the BBE and CB1 wheels of the LAr calorimeter, covering four entire Big Towers (BT=220,221 in BBE, BT=214,215 in CB1, in the hadronic part of the BT's in CB1 the series resistors were left in). The power supplies were re-adjusted to stand the higher current caused by the new hybrids (from 3.6 A to 4.8 A). Due to the slightly different rise time of the new preamps (about 50 to 100 ns, depending on the detector capacity) the trigger timing had to be re-adjusted for the four BT's as well. The range of adjustment required is well within the design specifications of the corresponding timing units and poses no problems for the foreseen upgrade.

After installation the noise of the new channels has been measured and compared to the measurements on the same channels before the change. The results for the electromagnetic calorimeter channels are shown in Fig. 5, separated into the two topological regions BBE and CB1. The measurements are presented as function of the channel capacity. One observes the same noise reductions as the ones measured in the laboratory tests at MPI (see above).

The ratio of the trigger cell noise between old and new preamplifiers is shown in Fig. 6. Again, the reduction observed is the same as in the calorimeter. These measurements prove that the noise is indeed dominated by the calorimeter cell capacities and that no additional noise is generated in the trigger electronics: The preamplifiers work as expected.

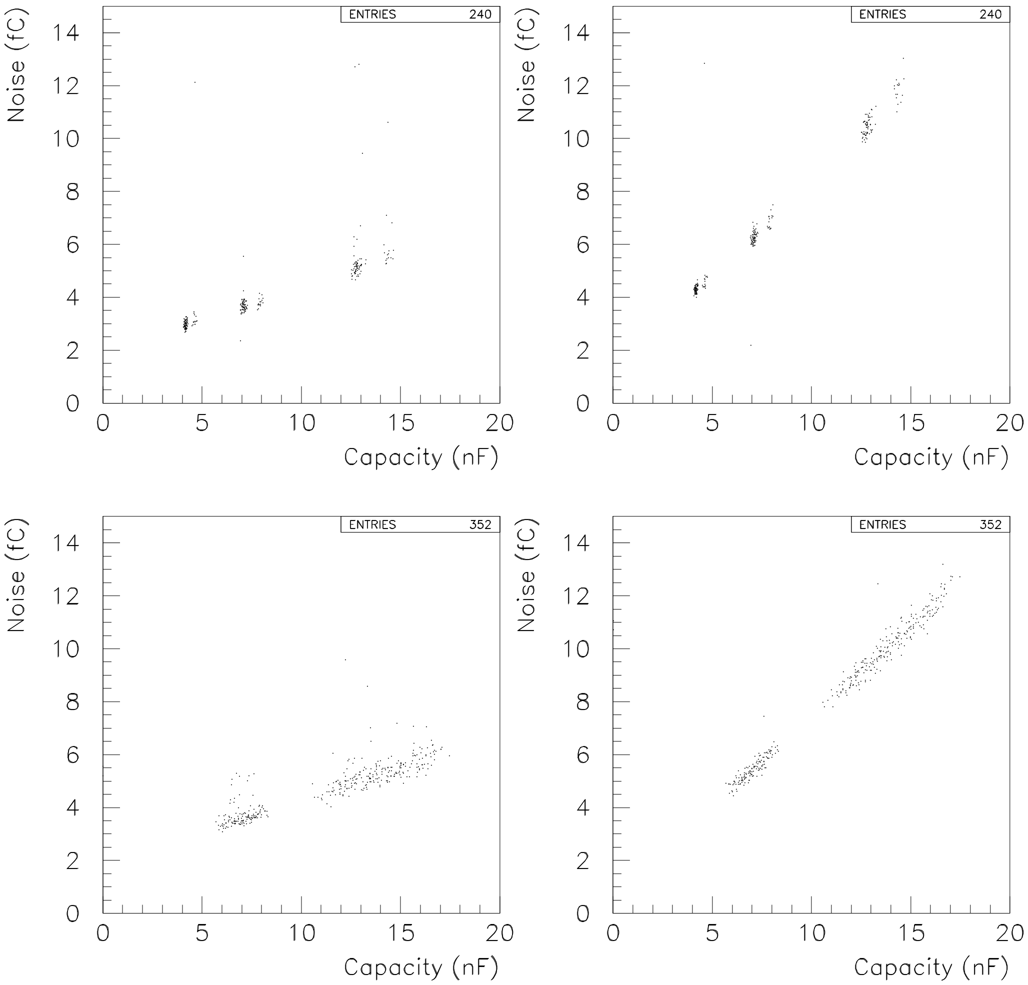

Figure 5: *Comparison of noise measurements from the LAr calorimeter (electromagnetic channels) between new (left) and old (right) preamplifiers as function of the channel capacity. The same noise reduction as the ones measured in the laboratory are observed.*

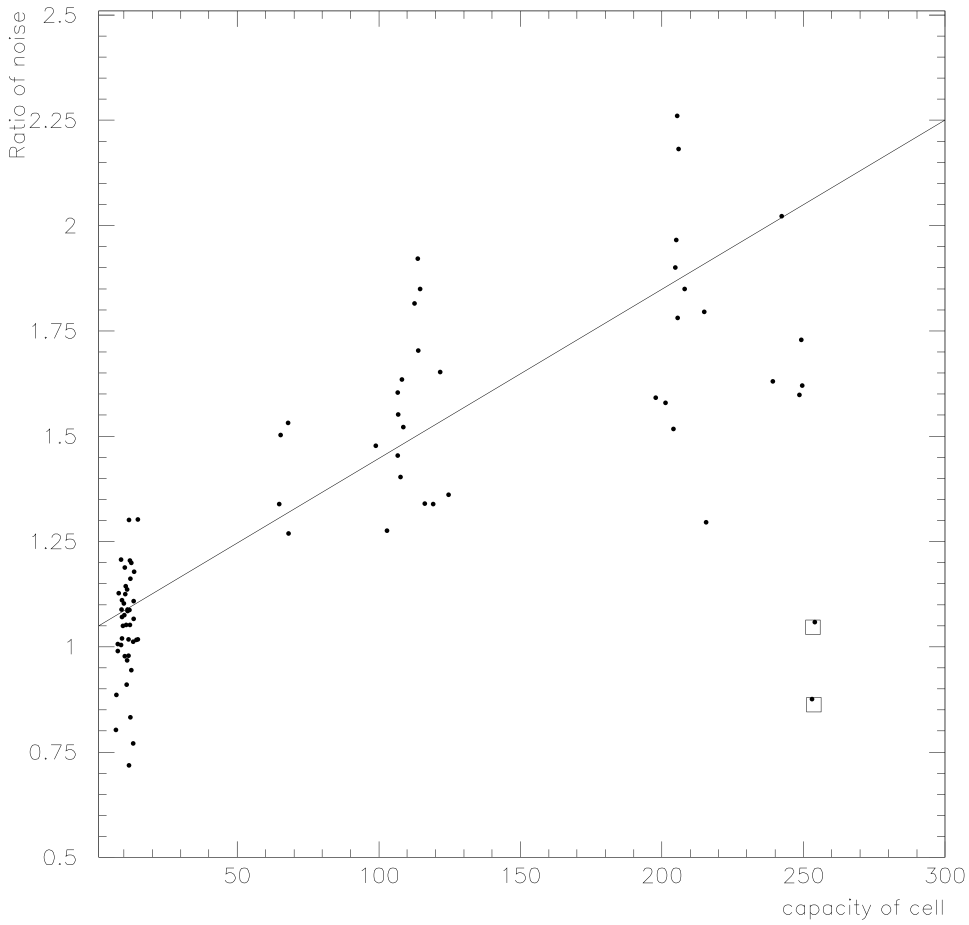

Figure 6: *Ratio of noise measurements in the electromagnetic trigger cells from the LAr calorimeter between old and new preamplifiers as function of the trigger cell capacity in nF. The same noise reduction as the ones measured in the calorimeter channels are observed. The larger scatter around the mean values (in comparison to the calorimeter channels) are due to the finite resolution of the trigger FADC's. The entries at 250 nF surrounded by squares correspond to known calorimeter channels subject to HV noise, which, of course, could not profit from the new preamplifiers.*

Partition	layer	channels
BBE	all layers	960
CB1+CB2	em1	1536
	em2	1536
CB3	em1	2048
	em2	2048
FB	em3	2048

Table 1: *List of channels to be equipped with new low noise preamplifiers*

Concerning the removal of the series resistors, we have not observed a single failure during the one month of running until the end of the luminosity period of 1995. We conclude that, at least under normal operation conditions of the calorimeter, the series resistor is not mandatory. We are aware, however, that the question of high voltage protection needs further study and we will launch a program of intensive investigation during the winter shut-down 1995/96.

5 Scope of Upgrade

We consider as an intermediate solution all electromagnetic calorimeter cells with a capacity greater than 5 nF for the exchange operation. This will be about 10000 channels. However, we should seriously investigate a staging scenario, where all electromagnetic cells and all hadronic cells in the barrel (CB and FB) with approximately 20000 channels would be exchanged. The merit would be a full factor of two noise and threshold reduction, as described in the physics section below. The hadronic channels are interesting, since they provide a possibility to trigger on minimum ionizing particles. Further study is required here, especially the question of reducing the series resistor for the hadronic channels in the CB, where no high-resistive coating is installed.

As an immediate step to be realized in the winter shut-down 1996/97 we propose to equip the high-capacity electromagnetic channels of the central barrel (CB and FB). A detailed list of channels to be equipped is given in Tab. 1. In order to thoroughly test the proposed upgrade we also propose to equip the entire BBE (960 channels) already in the winter shut-down 1995/96. We have enough hybrids at our disposal to complete the missing analog cards.

5.1 Preamplifier Production

The process of hybrid fabrication and replacement is the following: The hybrids will be fabricated at MPI, were a high-standard production line is available. On the existing analog cards, installed presently in H1, the old preamp hybrids are soldered out and replaced by the new preamp hybrid. This process will most likely be done in industry, where sufficient experience exists with such a delicate procedure. As a technical detail, the line resistors (20 Ohms) will also be removed (actually bridged, so that they can easily be put back in case of need. The rate of hybrid production, installation and test of the finished analog cards at MPI is estimated to about 100 ANCD's per week.

5.2 Analog Gating Modules

As stated above, the upgrade program of the LAr trigger includes, for full exploitation of the low noise electronics, a new AGM unit able to switch electromagnetic and hadronic trigger towers separately. At present, the AGM threshold is applied to the sum of electromagnetic and hadronic energy in the trigger tower. Since after exchange of new JFET's the noise in the electromagnetic parts will be comparable to the noise in the hadronic towers (old preamps), the AGM thresholds for the electromagnetic part can only be lowered by a factor two, if the signal comes from the electromagnetic part alone. Otherwise the achievable lowering is only a factor of 1.4. Since we would like to profit at the trigger level from the full noise reduction in the calorimeter, the channel separation is necessary. The new AGM unit also needs a new controller in the analog crates of the LAr trigger electronics. The target dates for these modules is likely to be the fall of 1996. The main characteristics of the new AGM modules are:

- separated discrimination of electromagnetic and hadronic channels
- precision of setting the AGM threshold: 1 mV (corresponding to 125 MeV on the electromagnetic scale)
- readout of AGM threshold via on-board ADC with high precision: 0.5 mV

5.3 Technical steps

In the following we give a detailed account of the various technical steps involved in the proposed upgrade program (intermediate solution) together with the foreseen scheduling for the particular actions.

1. Ordering of about 12000 JFETs from InterFet Corporation, Texas, in January 1996, to be delivered by July 1996
2. Design of new AGM module and controller card, spring 1996
3. AGM prototype end of April 1996
4. Test and, if necessary, redesign of AGM (June 1996)
5. Production of preamp hybrids at MPI from July to September 1996
6. Test of final AGM in H1 during September 1996
7. Test of hybrids during October 1996

8. Mass production of AGM and Controller modules starting October 1996
9. Extraction of ANCD's from H1 after end of Lumi period (probably December 1996).
10. Transport of ANCD's to MPI München, December 1997 to January 1997
11. Unsoldering of old preamp hybrids and insertion of new hybrids by industry (ready end of January 1997)
12. Test of ready-to-go ANCD's at MPI during February to March 1997
13. Transport of ANCD's to DESY end of March 1997
14. ANBX power supply adjustment, April 1997. The additional cooling power required is about 1.8 kW, which should not pose a problem to the installed water cooling system
15. Installation and test of ANCD's into H1, target date April 15, 1997
16. Timing check/adjustment (SSM) target date May 1, 1997
17. Installation and test of AGM's and controller units, May 1997

Following this schedule for the intermediate solution, the H1 calorimeter will be again fully operational and ready to take data by the end of May 1997.

6 The Physics Case

The proposed upgrade will lead to a substantial reduction of the noise in the LAr calorimeter readout, both for the high precision energy measurement and for the trigger. It will hence be easier to distinguish true energy deposits from electronic noise.

The benefit for the trigger is substantial and immediate because the level 1 trigger *rate* for all coincidences involving the calorimeter is presently dominated by *accidental* coincidences of the calorimeter with some other signal of H1, e.g. activity in the tracking devices. The reasons for this behavior are the large tower capacities and the coarse granularity in the LAr trigger. A reduction of noise and the finer granularity will reduce the likelihood for accidental coincidences and maintain the sensitivity for the signal.

We will discuss the benefits of the proposed upgrade for two extreme physics cases: single particles from heavy quark decays (electrons and muons) and jets. The results will be quoted either as a reduction of trigger rate - due to the reduced noise - or as a reduction of energy threshold maintaining the rate of the present setup.

In addition, we will quote the result for energy resolution for pions and electrons in the energy range from 1 GeV to 10 GeV. It will be shown that corrections for low energy deposits will be considerably smaller.

6.1 Reduced Noise in the LAr Trigger

The rates of the trigger elements built from the LAr trigger are largely dominated by the unavoidable noise induced by the capacity of the calorimeter. Typical rates are of the order of $1-10$ kHz for the trigger elements deduced from sums over large regions of the calorimeter (for energy threshold in the domain of 5-10 GeV), like e.g. the transverse (ET) energy or the total energy in the central (CB). The strategy adopted so far to reduce this rate to an acceptable level of a few Hz was combining information from independent detectors on sub-trigger level by the central trigger logic or even already when the trigger element is formed. The requirement of a track detected in the multi-wire proportional chamber geometrically pointing to a LAr Big Tower allowed, for instance, to set an energy threshold on the $2-3\ \sigma$ noise level. A Big Tower is built by merging the trigger cells such that it geometrically points to the interaction region (see Fig. 4).

The experience of the 1995 data taking revealed however the limitations of this strategy. Either physics triggers get very complicated and are therefore difficult to control, or the additional constraints cut unavoidably into physics. As example the missing transverse energy trigger is running sometimes at a rate of about $5-10$ Hz only because of random coincidences between a very loose track requirement (Zvtx-T0) and the corresponding LAr trigger element. With higher beam currents this rate is likely to increase even more. It is not desirable to limit this rate with more complex trigger requirements which almost inevitably will lead to more systematic uncertainty in efficiency.

Another challenging example are heavy quarks tagged by their lepton decay products having relatively low energy. For these processes the production cross sections are so low that one can not accept large prescale factors, but high statistics is needed in order to be able to discriminate the various production mechanisms.

Possible solutions are to refine the combinatorial power of trigger information, e.g. on level 2 (see below), where more time for the trigger decision is available, or to simply decrease the rate of the trigger elements. The concept of locally correlating energies and tracks is most important for photo-production and deep inelastic scattering at high y. In contrast to beam gas background tracks can be found pointing to the central part of the calorimeter. This is the region where noise is largest and which presently dominates the accidental rate. Since noise spectra have an exponentially falling behavior, large reduction factors can be achieved. The gain in trigger rate will be independent of the increase of beam currents which might be achieved by HERA in the future.

In Fig. 7 (left) this is illustrated for the energy spectra of the total sum over the central (CB) barrel and the total transverse and transverse missing energy in the event. The closed points represent the energy spectrum from background events triggered by requiring a minimal activity in the forward region of the detector (FwdRay-T0), overlayed as a histogram is the prediction of the LAr trigger Monte Carlo. The Monte Carlo simulation is able to model the gross features of the spectrum. The dashed line indicates the prediction for the full upgrade scenario, the dotted one for the intermediate solution. The achievable rate reduction can be directly read off from the integrated energy spectrum. In this representation for each bin the sum from this point onwards to the maximal possible value is given

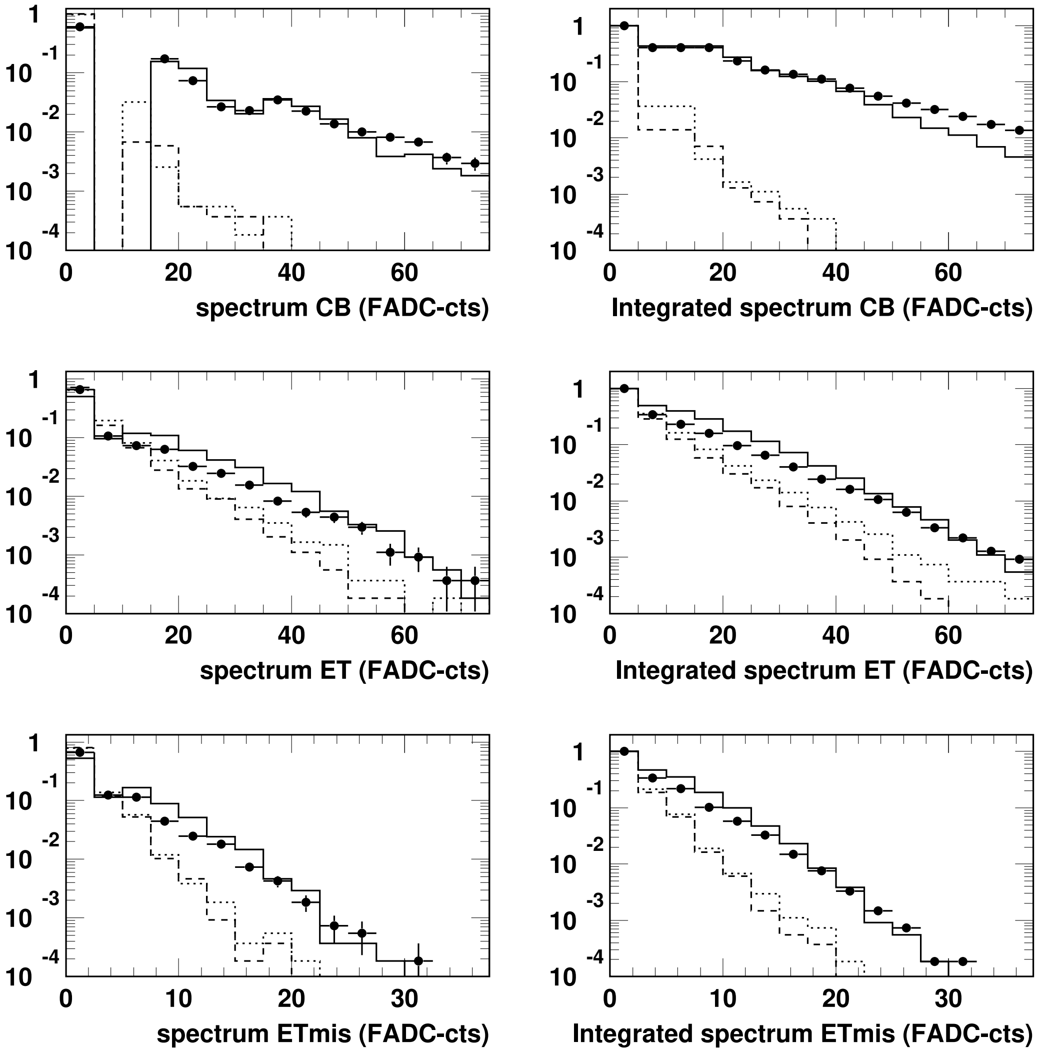

Figure 7: *Energy spectra (in units of 125* MeV*) for background events triggered by the* FwdRay-T0 *monitor trigger for the sum over all Big Towers in the central* (CB) *barrel, the total transverse energy* (ET) *and the total transverse missing energy* (ETmis). *On the left hand side the original energy spectrum is given, while the right hand side shows an integrated form. Data points are indicated as closed points, a Monte Carlo simulation is overlayed as a histogram. The dashed line gives the Monte Carlo prediction for the scenario using the new preamplifier in the whole barrel, the dotted one for the intermediate solution.*

which correspond to the fraction of events above a given threshold. For instance, in the central region (CB) having the largest capacities more than a factor of 500 can be gained, for a typical threshold of 40-50 FADC-counts, i.e. about 5 GeV. In the forward barrel region a factor of 20 can be reached for a threshold of 30 FADC-counts. This includes also a relaxing of the first (digital) Big Tower threshold from presently 16 FADC-counts, i.e. about 2 GeV, to a lower value as is shown for CB in Fig. 7 (left). A factor of 5 in rate reduction is achievable for the total transverse energy assuming a threshold of 40 FADC-counts and even a factor 10-20 for the total transverse missing energy (at 20 FADC-counts). These large reduction factors will avoid a possibly necessary down-scaling of the total energy triggers designed to catch all (genuine HERA) events produced in deep inelastic scattering at very high momentum transfer allowing moreover to keep the full sensitivity for any possible new physics detectable at HERA.

In addition, this will ensure in future the triggering of two jet events produced in proton-photon collisions where the scattered electron escapes detection. Typical efficiencies, reachable with thresholds given above, amount to 70% for jets with transverse energies of 10 GeV for a range in pseudo-rapidity from 0 to 2.5 [1]. Even if one decides not to register all events of this kind on tape, this leaves the possibility to design physics triggers for special event topologies, such as events having the jet from the photon remnant in backward part of the H1 detector. These events are particularly interesting to get insight into the parton content of the photon.

Various QCD effects can be studied using the J/ψ signal. Its elastic and diffractive production mechanisms allow to get insights into the coupling of the photon to the J/ψ and into the nature of the Pomeron. The inelastic production of the J/ψ offers an excellent opportunity to extract the gluon density of the proton. Here, the optimal exploitation of the interesting kinematic region of low x requires an optimal detection in the central and backward part. This could be ensured by a low noise LAr calorimeter together with the backward detectors of H1. However, before attempting to measure the gluon density, a sample of events with large statistics is needed to test the different models of the production mechanism on various differential distributions. Therefore efficient triggering leading to event samples with reasonable statistics is necessary.

Even the case of elastically produced J/ψ where one can profit from the special topology of the decay particles was not fully covered in the 1995 data taking period and suffered from prescaling. Especially in the case of the J/ψ decaying into electrons the LAr trigger plays a crucial role, since the track triggers alone are not able to efficiently operate in the high background environment of HERA. Here any gain in efficiency or possible reduction of the presently large prescale factor is of great interest. The sensitivity to low energy electrons has only been reached in 1994 by imposing that a Big Tower be validated by a track in the multi-wire proportional chamber geometrically pointing to it already before forming the trigger element called LAr bigray (see for details [1]).

Within the polar acceptance from 20^o to 160^o the energy spectrum of the electrons from the J/ψ decay is peaked around 1.5 GeV with a tail up to 4 GeV. With the present electronics this is just in the region of the threshold discriminating signal from noise for the Big Towers. This is illustrated in Fig. 8a (closed points), where the threshold behavior of the Big Tower signal is shown. An efficiency of 50% is

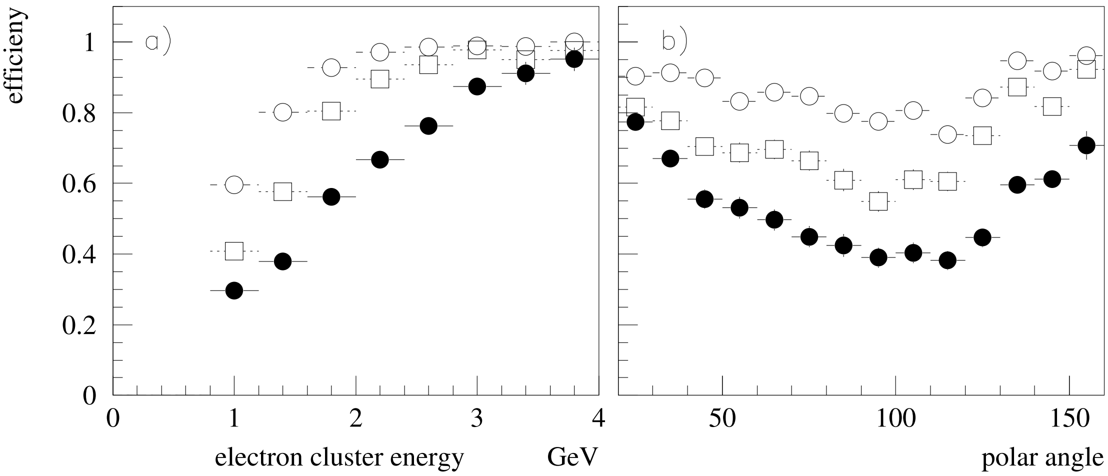

Figure 8: *a) Efficiency as a function of the energy measured on the electromagnetic scale in the calorimeter to fire a Big Tower for $J/\psi \rightarrow e^+e^-$ events calculated from a Monte Carlo simulation. Shown is the present situation (closed circles), the improvement expected by the full upgrade (open circles) and the intermediate solution (open squares). b) Efficiency as function of the polar angle θ (in degrees), for the present preamplifier (closed circles), the upgrade (open circles) and the intermediate solution (open squares).*

only reached at about 1.8 GeV and the threshold is relatively wide. In the proposed scenario the trigger thresholds can be lowered proportional to the noise reduction without increasing the trigger rate, since in both cases the thresholds are assumed to be set at 3 σ. When one replaces, e.g. all preamplifier in the barrel, this results in a threshold reduction of a factor of 1.8 in the electromagnetic LAr section and a factor of 1.4 in the hadronic LAr section. Monte Carlo simulations including both, reduced noise and lower trigger thresholds, yield the threshold behavior shown in Fig. 8a (open points). The open squares indicate the achievable efficiency for the intermediate solution. For low energetic electrons from J/ψ decays the probability to fire a Big Tower is in the full upgrade scenario increased by a factor of 2, i.e. the 50% efficiency point is already crossed at 0.9 GeV when all preamplifier are replaced and at 1.1 GeV in the intermediate solution scenario.

The Big Tower efficiency as function of the polar angle θ for electrons depositing at least 0.8 GeV in the calorimeter is shown in Fig. 8b for the present situation (closed points), the full upgrade (open points) and the intermediate solution (open squares). The energy distribution of electrons from J/ψ decays exhibit a minimum around $\theta = 90^0$ causing the observed minimum in the efficiency curve as function of θ. The expected gain in efficiency is more then 100% over a large polar range for the fully equipped calorimeter, while for the intermediate solution the resulting efficiency lies in between.

For the detection of J/ψ decaying into muons, which was finally possible in 1995 the LAr trigger could act as an additional constraint to bring the sub-trigger rate to an acceptable level and in addition would open the possibility to trigger on muons with low momenta. This would help particularly in the case of inelastically produced J/ψ where a low multiplicity requirement can not be imposed. This however assumes

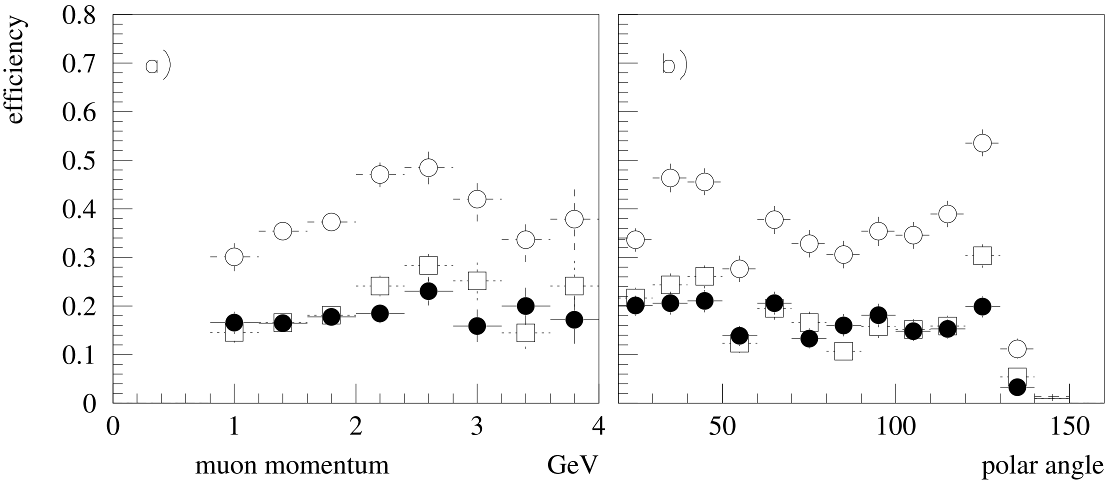

Figure 9: *a) Efficiency as a function of the energy measured in the calorimeter on the electromagnetic scale to fire a Big Tower for $J/\psi \rightarrow \mu^+\mu^-$ events calculated from a Monte Carlo simulation for the present preamplifier (closed circles), the full upgrade (open circles) and the intermediate solution (open squares). b) Efficiency as function of the polar angle θ (in degrees), for the present preamplifier (closed circles), the upgrade (open circles) and the intermediate solution (open squares).*

the possibility to trigger on minimal ionizing particles in the LAr which can be made possible by using the new preamplifier and by increasing the granularity by the new AGM modules.

The main physics triggers for the channel $J/\psi \rightarrow \mu^+\mu^-$ are based on signals in the muon detectors. However, due to the energy loss of the muons in the material in front of the iron only muons with a momentum above approximately 2 GeV are able to penetrate to this outer detector part. On the other hand, it has already been shown that an efficient identification of muons below 2 GeV is possible with the LAr calorimeter. Therefore it is desirable also to investigate the possibility to trigger these low momentum particles.

Muons passing through the LAr calorimeter deposit an energy of about 1 GeV on the electromagnetic scale. For these low energies the Big Tower efficiency for the present trigger thresholds is below 20% as shown in Fig. 9a (closed points). Again, the fully equipped barrel would allow an efficiency gain of about 100%. This opens the nice possibility to design a physics trigger for low momentum muons using the LAr. The intermediate solution, however, does not at all improve the situation. In this case, also the noise of the hadronic cells has to be reduced.

As already discussed above, the gain in the trigger rate due to lower noise in the calorimeter ensures in future the data taking of charged current deep inelastic scattering events without disturbing the other physics programs carried at H1. One can, however, rise the question about the gain in efficiency, if one assumes a constant trigger rate. Fig. 10 shows the present threshold behavior parameterized as function of the reconstructed missing transverse momentum in the event. Due to the small cross-section of charged current events, the data points (open circles) are deduced from neutral current events taken in 1995 where the electron has been artificially removed and which were then re-weighted to the charged current cross section [6].

A charged current Monte Carlo prediction is overlayed as a histogram. The nice agreement between data and Monte Carlo gives confidence in the extrapolation to the low noise scenario shown as dashed (dotted) line assuming in addition a global trigger threshold lowered by a factor 1.4 (1.7) and the trigger tower thresholds fixed to 3 σ in both cases. The reduction factors of the global threshold assumed here can be read off Fig. 7. For instance, when only one out of 10000 (1000) background events is allowed to pass, the threshold has presently to be set to 30 (26) FADC-counts, while for the upgraded calorimeter 20 (18) FADC-counts are possible. The point of 50% efficiency for the missing transverse energy trigger is shifted from 13 GeV to 7 GeV and the threshold becomes sharper allowing to extent the analysis (presently restricted to 25 GeV) to missing transverse energies down to 15 GeV. This change is significant for measuring the helicity structure of the charged current for which the phase space coverage in y is important. For partial change of the preamplifier these results do not change significantly (see also Fig. 7).

H1 has installed potentially powerful second level trigger systems. They are based on a *neural network* approach and *topological correlators*. These devices use the energy at the Big Tower level and thus profit from the lowest possible thresholds. Coarsely speaking the energy "fine structure" of the event can be used in conjunction with information from other detectors. Presently the thresholds are so high that little information is added to the global energy information of the first level.

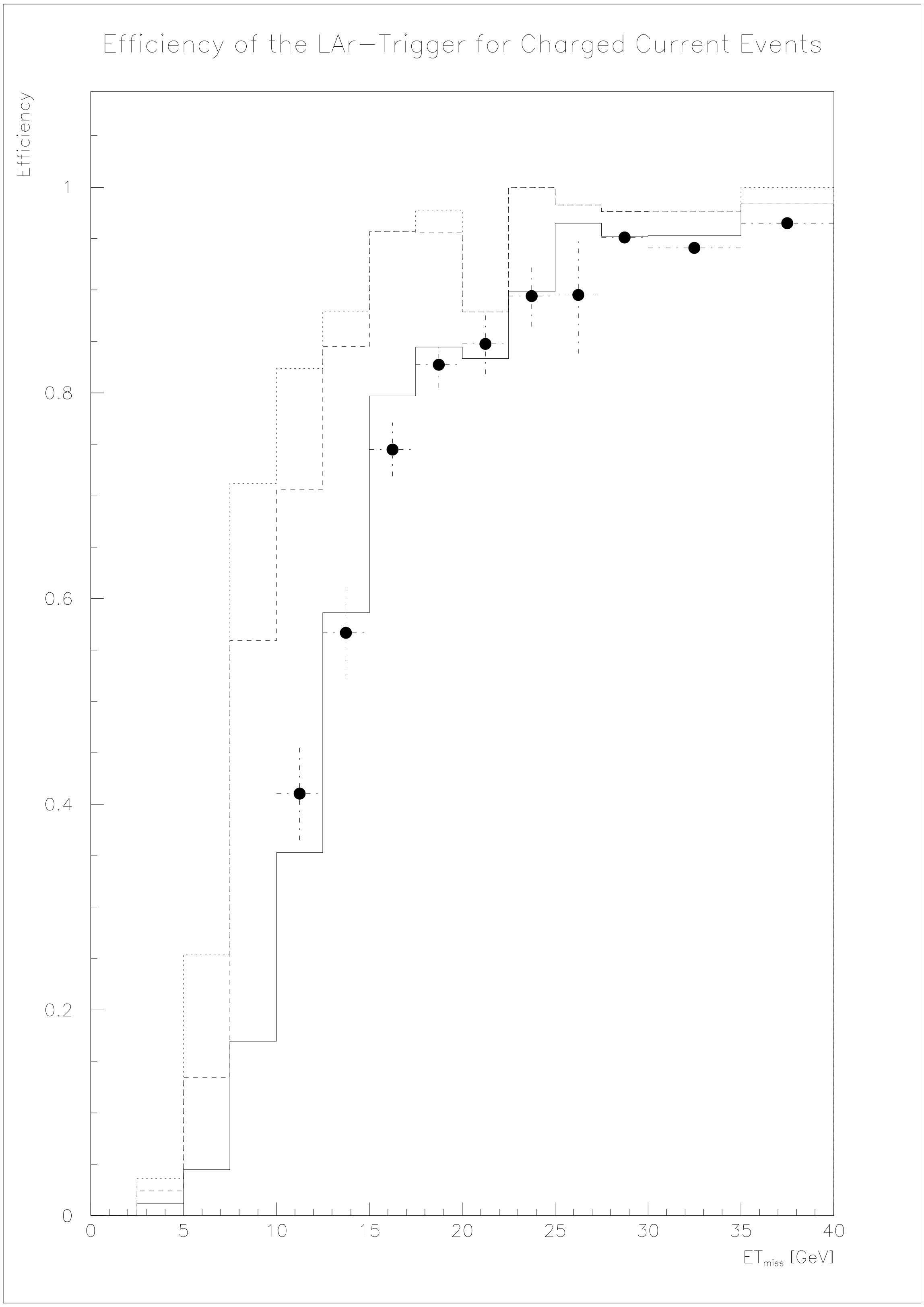

Figure 10: *Efficiency of the missing transverse energy trigger element in function of the reconstructed missing transverse energy calculated for data (closed points) and Monte Carlo (histogram). Overlayed is a Monte Carlo prediction for the low noise upgrade scenario and a reduction of the global threshold by a factor of* 1.4 *(dashed line) and* 1.7 *(dotted line).*

6.2 Reduced Noise in the LAr Readout

The reduced noise in the calorimeter together with a reduced noise cut, which is usually applied in terms σ already during data taking and on the reconstruction level as well, effects both the energy resolution and the linearity of the energy. This is particularly important at low energies.

In Fig. 11a the relative energy resolution $\sigma(E)/E_{true}$ for electrons is plotted for the present preamplifier (closed points), the full upgrade (open points) and the intermediate solution (open squares). For 1 GeV electrons a slight improvement of the energy resolution can be realized. However, a significant gain can be obtained for the relative deviation of the measured energy from the true energy (linearity $(E_{meas.} - E_{true})/E_{true}$) as shown in Fig. 11b. In case of new preamplifier in the entire barrel, the linearity for electrons with energies from 1 to 10 GeV can be kept within 2%. Since the present deviations from linearity can be as large as 4%, this represents an improvement of a factor of 2. Besides obvious improvements in mass resolutions or energy flow measurements, this could lead to a significant better particle identification in the low energies domain. This is e.g. important for electrons from heavy quark decays, where the energy/momentum ratio gives the most powerful electron/pion separation.

For pions a similar behavior of linearity and resolution is observed (see Fig. 12a and b. Here the gain at low energies will be of great benefit for many physics analysis, since the average energy deposit is of the order 400 to 800 MeV for hadrons and photons produced in a typical deep inelastic scattering event at low momentum transfer. Presently, on average, 17% of the energy carried by those particles is lost due to the high noise cuts. As example, the improvement in reconstructing the basic kinematic variable y using only the hadronic final state (method of F. Jacquet and A. Blondel) is illustrated in Fig 13a. The observed shift of about 20% using the presently available calorimeter completely vanishes in case of the full equipment of the barrel and is reduced to about 10% for the intermediate scenario. This helps to reduce the systematic errors in the structure function measurement relying on the Jacquet-Blondel at low y. Although the y resolution is not significantly improved, the annihilation of the y shift alone will allow to reduce the dependence on the Monte Carlo normally used to correct the data for such effects.

The comparison of the transverse momentum of the scattered electron and as reconstructed using all energy deposition in the LAr calorimeter is one of the main handles to control the energy calibration. A calorimeter with less white noise is more sensitive to deposition of low energies and allows therefore to reduce the observed systematic shift. The remaining shift of about -0.2 GeV is due to particles absorbed in the material before the calorimeter or were emitted outside the acceptance. Presently, the control of the absolute energy scales relies on a modeling of the data by the Monte Carlo. The upgraded calorimeter thus helps to improve the understanding and control of the absolute energy scale and to reduce the model dependence introduced by the detector simulation.

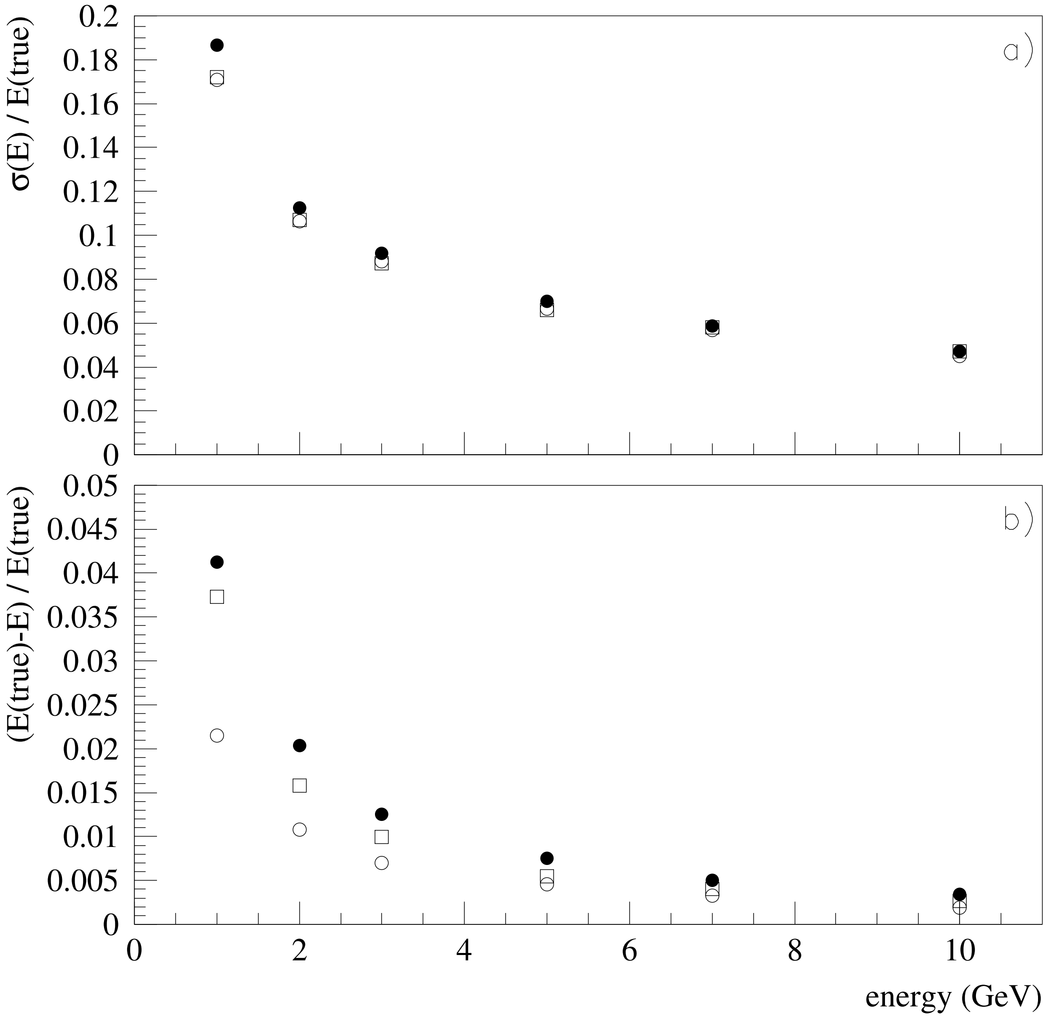

Figure 11: *a) Energy resolution of electrons as function of the energy for the present preamplifier (closed circles), the full upgrade (open circles) and the intermediate solution (open squares). b) Relative deviation of the measured energy from the true energy (linearity) for electrons as function of the energy for the present preamplifier (closed circles), the upgrade (open circles) and the intermediate solution (open squares).*

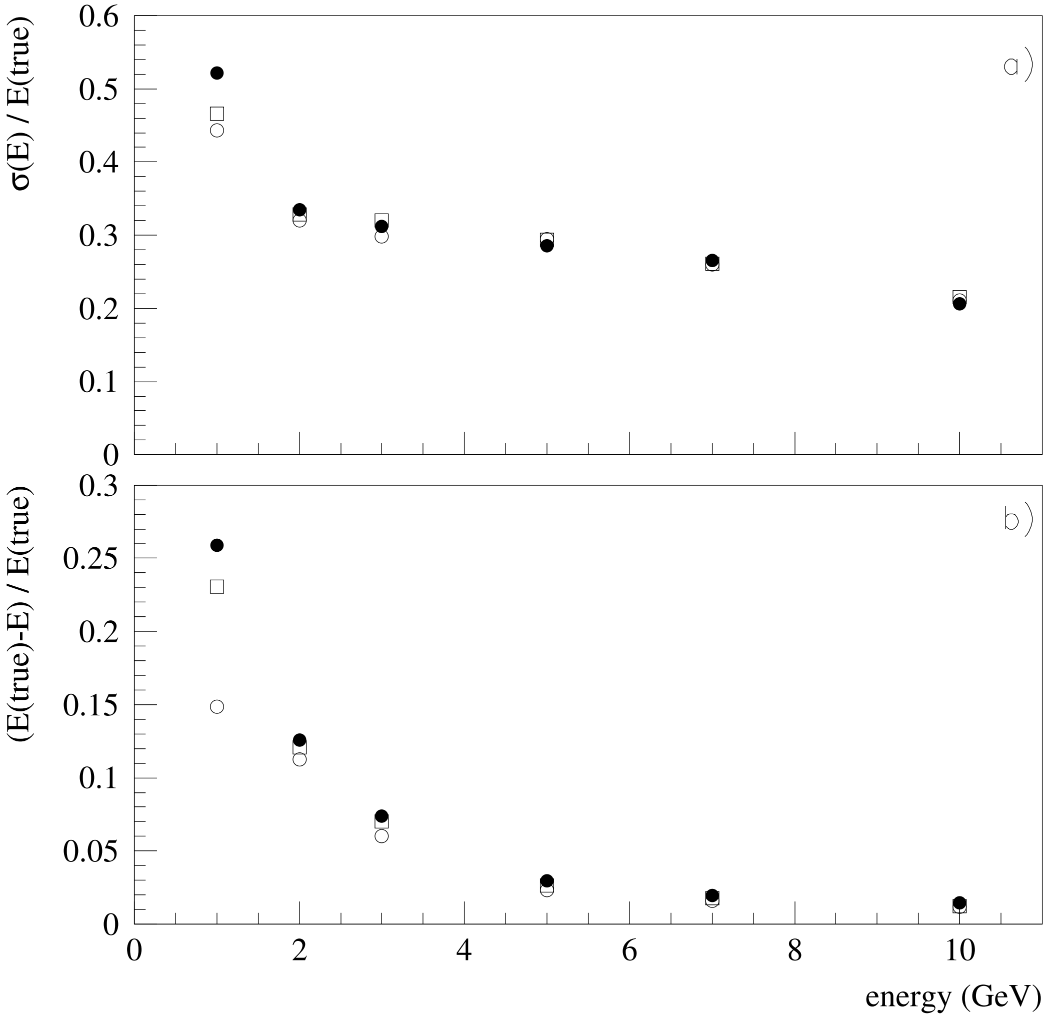

Figure 12: *a) Energy resolution of pions as function of the energy for the present preamplifier (closed circles), the full upgrade (open circles) and the intermediate solution (open squares). b) Relative deviation of the measured energy from the true pions for electrons as function of the energy for the present preamplifier (closed circles), the upgrade (open circles) and the intermediate solution (open squares).*

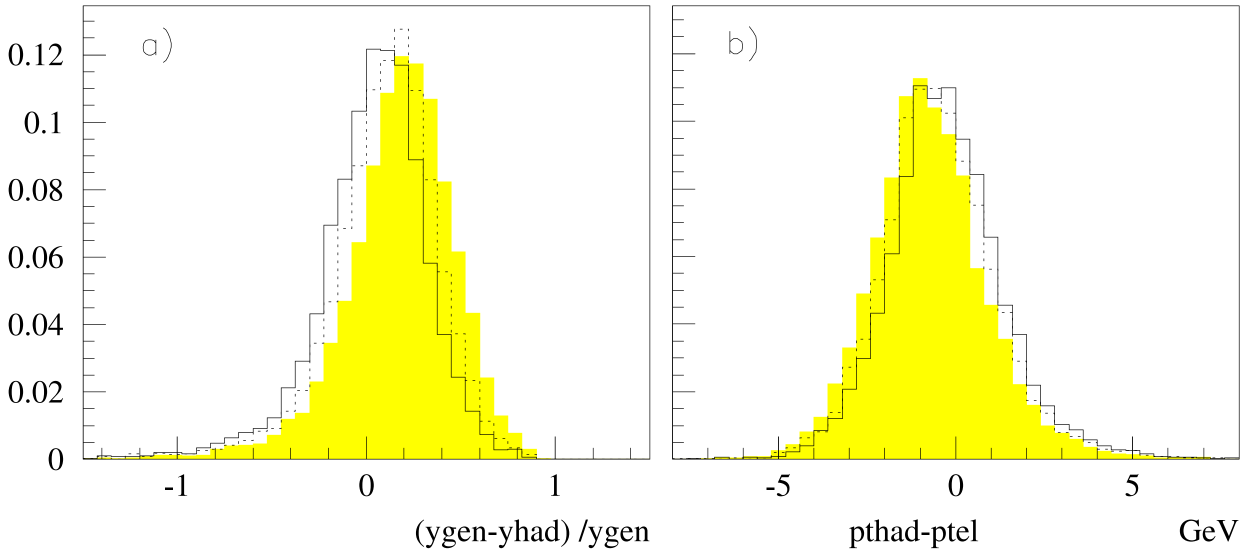

Figure 13: *a) y resolution (Jacquet-Blondel) for low Q^2 deep inelastic scattering events for the present preamplifier (shaded histogram), the full upgrade (full line) and the intermediate solution (dotted line). b) Difference of the transverse momentum as measured by the hadronic final state and the scattered electron for the present preamplifier (shaded histogram), the full upgrade (full line) and the intermediate solution (dotted line).*

7 Cost

In the following the costs for a single channel are summarized. The dominating factor is the JFET, amounting to about DM 15.-, when bought in large quantities (more than 5000 pieces). The parts for the hybrid are about DM 4.- including the hybrid production at MPI, and the unsoldering and re-soldering of the hybrids in industry is about DM 4.-. The total costs per channel is therefore DM 23.-.

We envisage to equip 10000 channels and have to procure a sufficient amount of spares for potential repair. A reasonable safety margin is 20 %. We therefore will order 12000 pieces from InterFET, fabricate the corresponding hybrids, but will equip only 10000 channels.

The AGM module (100 VME modules) and the crate controllers (25 modules) are estimated to about DM 150000.-

The total costs for the proposed upgrade (intermediate solution) is given in Tab. 2

The financing will be done by MPI (DM 150000), the University of Dortmund (DM 100000), and the University of Brussels (about DM 30000). The missing DM 130000 will be financed from the operations fund of the calorimeter group.

12000 JFET's	180000
10000 installed hybrids	80000
AGM's + Controllers	150000
Sum	410000

Table 2: *Total cost in DM for proposed upgrade (intermediate solution)*

8 Summary

We propose an upgrade of the LAr calorimeter front end electronics, which is suited to substantially reduce the noise in the LAr trigger. The proposal envisages to equip the large capacity channels in the calorimeter with new preamplifiers based on low noise JFET's, which have become available recently. As a consequence we gain a higher sensitivity to low energy depositions in the trigger as well as in the calorimeter proper.

We have successfully tested the new preamplifiers in the actual experiment during November of 1995 and found their performance according to the expectations. As an intermediate step we propose to upgrade 10000 of the 20000 high capacitiy channels in the calorimeter during the next winter shut-down 1996/97. The upgrade program also foresees to increase the granularity of the trigger towers by new analog gating modules. The funding for the intermediate step is solidly ensured by the collaborating instutions and the calorimeter group of the H1 experiment.

References

[1] T. Carli et al., The Performance of the LAr Trigger in 1994, Internal H1 note, H1-07/95-445 (http://dice2.desy.de/inotes/h1-0795-445) and contribution to the Int. Europhys. Conf. on HEP, eps0644, Brussels, July 1995.

[2] V. Radeka, *Low Noise Techniques in Detectors*, Annual Review of Nuclear and Particle Science, Vol. 38 (1989) 217; *Speed and Noise Limits in Ionization Chamber Calorimeters*, Nucl. Instrum. Methods A265 (1988) 228.

[3] C. Pascaud, LAr calorimeter calibration and noise measurements, H1 internal notes H1-06/92-222 and -229.

[4] Datasheet of the JFET 2 SK 372, Toshiba Corporation, Japan

[5] Data book by InterFet Corporation, JFET NJ3600, Garland, Texas, USA

[6] H1 Collaboration, Measurement of the e^+ and e^- Induced Charged Current Cross Sections at HERA, DESY 95-102.