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LIQUID ARGON CALORIMETRY AT THE H1 EXPERIMENT

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The readout cells of the liquid argon (LAr) calorimeter for the H1 experiment at HERA are described. Some relevant properties of LAr for calorimetry are discussed. Results on energy resolution with the weighting technique are presented.

1. Introduction

The measurement of structure functions at the HERA electron-proton collider requires an absolute energy calibration of the measured hadronic energy at the 1-2% level. In addition, good e-π separation and missing energy measurements are needed. From these requests the properties of the calorimetry should be the following:

- Good absolute calibration.
- Good hermeticity.
- Good transverse and longitudinal segmentation.
- Good energy resolution.

These requirements are best fulfilled by a fine segmented LAr calorimeter. A detailed description of the calorimeter and the H1 detector is given in ref. [1]. In this article we will concentrate on the readout structures of the H1 calorimeter and on some more general questions in LAr calorimetry.

2. HV coupling

As shown in fig. 1 the high voltage can be connected to either side of a LAr gap. In both cases the coupling or blocking capacitance C_B should be large compared to the capacitance C_{LAr} of the LAr gap. For typical calorimeters blocking capacitors in the range of 100 nF are needed. These capacitors must be positioned inside the cryostat. They are bulky and expensive.

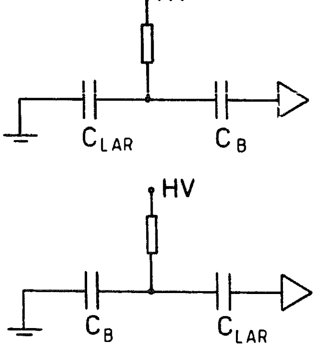

Fig. 1. The two different types of high-voltage coupling. C_B must be large compared to C_{LAr}.

To overcome this difficulty, these blocking capacitors are incorporated into the readout structure. For the major part of the H1 calorimeter the high voltage is supplied to the surface of a Kapton foil by high resistive coating (HRC). The Kapton foil is glued onto the converter. This blocking capacitance is typically 30 times larger than the capacitance of the LAr gap. This means that 97% of the available charge is coupled to the amplifier. The HRC consists of a mixture of Epoxy and soot. It is either printed or painted onto the Kapton surface. The resistivity is some MΩ/sq. The typical diffusion speed of the charge is 10 μs/cm^2. This limits the crosstalk along the high-voltage layers. An additional advantage is the limited power of high-voltage breakdowns.

3. The readout structures of the H1 LAr calorimeter

The converter material for the H1 calorimeter was choosen to be lead for the electromagnetic and stainless steel for the hadronic calorimeter.

As shown in fig. 2a the lead calorimeter stacks are assembled with alternating high-voltage plates and pad plates. The lead of the high-voltage plates is stabilized from both side with copper-cladded G10 plates. The high voltage is connected to the HRC at the Kapton layers. The whole sandwich is glued with prepregs on Epoxy basis. The pad plates have a similar structure as the high-voltage plates. The G10 readout boards are printed boards with a pad structure at the surface and with readout lines from the pads to the circumference of the sandwich at the opposite side.

The hadronic stacks are fabricated from 16 mm thick stainless steel plates. Into the gaps, which are of 12 mm thickness, independent readout boards are inserted. The

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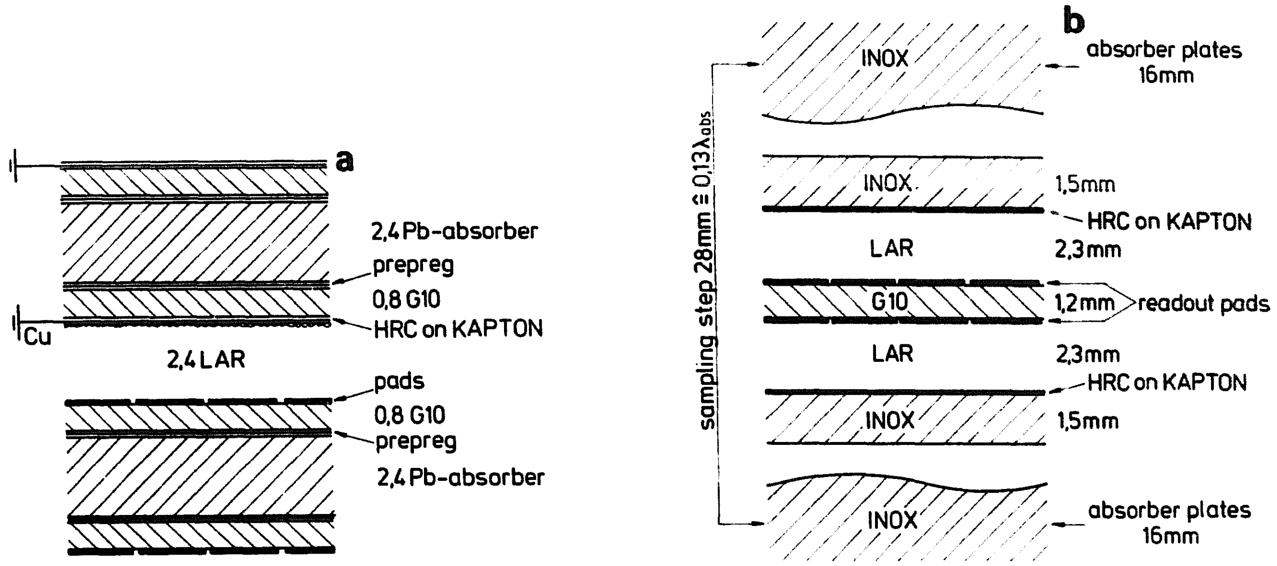

Fig. 2. (a) The readout structure of the electromagnetic stacks; (b) the readout structure of the hadronic stacks.

structure is shown in fig. 2b. Similar to the electromagnetic stacks the high voltage is connected to the HRC on Kapton. The readout board in the center of the LAr gap has a pad structure on both sides. By this construction technique the unflatness of the converter plates does not effect the thickness of the LAr gap.

Depending on the angle the longitudinal segmentation of the calorimeter is 7–9-fold. The total number of channels is 45 000.

4. Some properties of LAr relevant for calorimetry

LAr is widely used as a readout medium in sampling calorimeters. It is also a good candidate for calorimetry at the future large hadron colliders. The long-term stability and the radiation hardness is excellent. The charge collection time is with several 100 ns quite long. On the other hand, acceptable signal-to-noise ratios can be obtained [2] with short shaping times.

5. Compensation and e/π response ratio in LAr calorimeters

For a good energy resolution and a correct measurement of jet energies it is important, that the response to electrons, photons and pions is equal. This e/π response ratio depends on the converter material, the sampling ratio and the particle energy. Values between 1.0 and 1.4 were measured in different test setups for LAr. A compilation of values is given in ref. [3]. The values closest to 1 were reached with the D0 uranium LAr calorimeter, where values between 1.07 and 1.02 were reported [4]. For the lead LAr and iron LAr calorimeter of H1 the e/π ratio was measured [5] to be 1.1–1.3. Several attemps were made by different groups to tune the e/π ratio to lower values.

With the admixture of hydrogenous additives like methane the neutrons can be detected via elastic scattering. On the other hand, the Birks kB factor increases dramatically [6] by admixtures of methane. This results in an increasing e/π ratio with methane concentration [4].

It was also tried to reduce the electron response by tuning the "transition effect" with additional layers at the surface of the converter plates. For silicon readout very encouraging reductions in the electron response of up to 29% were achieved experimentally [7] by introducing additional G10 plates. Taking into account the reduction of the hadronic response by 10%, the range of tuning the e/π ratio for silicon readout is 0–20%.

For LAr readout however, EGS MC calculations [8,9] have shown very small effects for realistic gap dimensions. For cladding of uranium with aluminum or copper, effects of less than 1.5% have been found. From these simulations we conclude that the e/π ratio of LAr calorimeters can be tuned in the range of a few % only by cladding the converter plates.

A significant contribution to the signal of hadronic showers are n, γ reactions [10,11]. For calorimeters with iron or lead absorbers the range of the neutrons is large compared to the converter thickness. By cladding the converter surfaces with gadolinium paint or with cadmium, the emission of γ's from n, γ reactions becomes concentrated close to the LAr readout with the consequence of a reduced e/π ratio. With energies around 3 MeV the produced photons have ranges in the

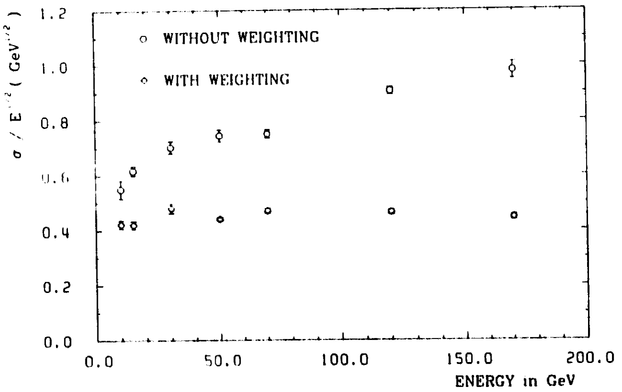

Fig. 3. The measured energy resolution for pions with and without weighting.

order of 2 cm, with the consequence that sizable reductions of the e/π ratio can only be achieved with quite thick converter plates.

6. Energy weighting and H1 test results

The e/π ratio will be 1.1–1.3 for the H1 LAr calorimeter. Without further corrections this limits the energy resolution for pions mainly at large energies. It was demonstrated by the CDHS Collaboration [12] that it is possible to develop from the longitudinal shower profile an algorithm which attributes different weighting to different parts of the shower amplitudes on an event-by-event basis. This weighting technique was further developed [5,13] and it was shown that e/π ratios equal to 1 can easily be reached. The energy resolution for high energies can considerably be improved, which is reflected in a small constant term in the energy resolution. The energy resolution for pions for a test setup equivalent to the H1 LAr calorimeter structure is shown in fig. 3 with and without weighting. The weighted energy resolution is well below $50\%/\sqrt{E}$ for all energies [5].

7. Jets versus single particles

The calorimetric jet energy measurement at HERA must be independent from the jet topology and the jet multiplicity. With compensating calorimeters this request can easily be fulfilled. Noncompensating calorimeters rely on a correct energy weighting procedure.

Within the H1 Collaboration mainly three different approaches are followed:

1) MC simulation of the shower development of different topology jets with a weighted analysis of the deposited energies. Energy deviations between different jets, electrons and single pions were found to be less than 2% at high energies [1]. To this value some systematic error from the imperfect tuning of the MC must be added.
2) Production of jets in a converter just upstream of the test calorimeter. These test measurements were performed in a test beam at the CERN SPS.
3) Construction of jets from single particle showers measured at the test beam. This is in principle the cleanest methode to determine the jet response.

The present and future work will continue to produce a consistent picture from these different approaches.

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