The ACCORDION Calorimetry for LHC

Irène Vichou
LAL Orsay
Université Paris-Sud
91405 Orsay, FRANCE
Representing the LARG Group of the ATLAS Collaboration

ABSTRACT

One of the basic elements of the ATLAS experiment for LHC is very good calorimetry. The liquid ionization and the 'Accordion' technique is an adopted choice. A review of recent progress on building and testing the performance of such calorimeters is presented here, covering the em barrel sector prototype –standalone and equipped with a separate or integrated preshower–, as well as the em endcap and hadronic barrel prototypes.

1 Introduction

The ACCORDION Calorimetry, which is too often mentioned in this paper, stems out of the idea of using accordion-shaped electrodes in liquid ionization calorimeters. Such an approach seemed attractive for LHC and a large R&D activity was launched giving nice results in beam tests, which in turn were exploited to design a performing em calorimeter system for the ATLAS experiment.

At LHC calorimetry is a critical issue due to stringent requirements dictated either by physics performance or by difficult experimental conditions [1]. Concerning physics, not only a very good energy resolution is needed, but also good position measurement and ability to cover a wide dynamic range and geometrical acceptance. On top of that LHC will offer a very high luminosity of $10^{34} cm^{-2} sec^{-1}$, implying a big amount of pile-up (23 soft interactions per event) and high neutron and gamma fluxes. Thus a calorimeter for LHC should be highly performant, fast, fine-grained and resistant to radiation.

A good choice for all the above is a liquid ionization calorimeter exploiting the novel idea of D.Fournier to use accordion shaped electrodes and absorber plates with their zig-zags running parallel to the shower axis [2]. The use of liquid Ar as active medium and radiation resistant front-end electronics makes the system radiation-hard. The high readout speed is achieved by the use of only the fast rise of the signal pulse in the LAr and by the clever transmission of the signal by the accordion electrodes themselves to the preamplifiers. The calorimeter cells are defined in one direction by etching strips on the electrodes and in the other by grouping electrodes together. Thus there are no cracks between cells, high granularity (also low detector C and low noise) is easily achieved and the number of connections (also the inductance) are minimised.

The performance of several prototypes having used the accordion technique will be presented in the following sections, showing that they also meet the physics requirements set for various channels, e.g. the $H \rightarrow \gamma\gamma$ channel.

2 Accordion EM Barrel

A very good test of the above characteristics was carried out with the construction by the RD3 collaboration of a large scale LAr em calorimeter prototype with a fully projective structure which was envisaged as a sector of the ATLAS barrel calorimeter [3]. Its length along the z-axis (LHC beam axis) is 2m, corresponding to pseudo-rapidity range $0 \leq |\eta| \leq 1.08$, and it covers 27^o in azimuth (ϕ). The total thickness at $\eta = 0$ is $25X_0$'s, segmented longitudinally in three parts(9/9/7 respectively). The Pb accordion-shaped absorbers are 1.8 (1.2) mm thick for $\eta < 0.7 (\eta > 0.7)$ to compensate for the lower sampling fraction at higher η's. The electrodes are copper-kapton boards separated by 1.9 mm LAr gaps from the absorbers. The granularity is 0.020 in ϕ, defined by grouping three kapton boards, and 0.018 in η which is the width of the etched electrode strips.

The front-end/readout chain of the calorimeter consisted of cold or warm preamplifiers followed by shapers with 38 nsec shaping time (that value is a compromise between the electronics and pile-up noise for LHC). The signal is then sampled at the peak and digitised by a 12bit ADC. The noise from the electronics for such a fast shaping is $\approx$ 300 MeV for a region containing an em shower. Muons can be detected with a signal-to-noise ratio of 4 in a region of two em towers.

The em barrel prototype showed the following properties when exposed and scanned with electron beams

Figure 1: *The em barrel module prototype under construction.*

of various energies. The energy resolution at two different η points corresponding to two different absorber thicknesses can be shown in figure 2. The sampling

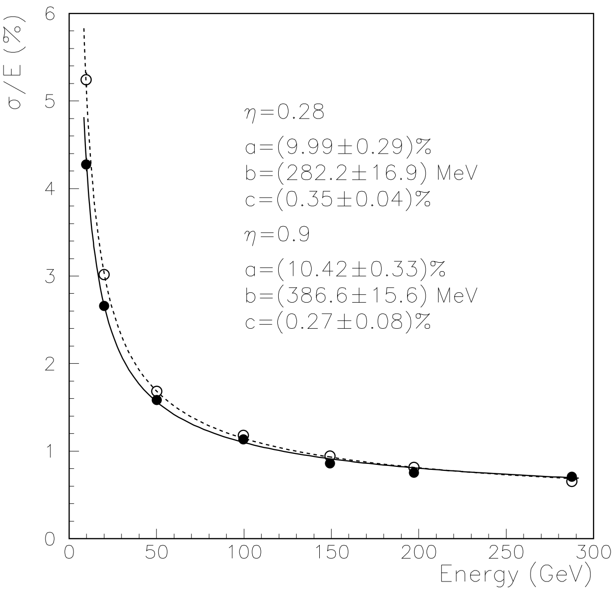

Figure 2: *The energy resolution curve for the em barrel prototype.*

term $(a/\sqrt{E})$ is similar for the two positions. The constant term (c) of the resolution is due to local imperfections in the cell. Its value of 0.3% is residual after the relevant geometrical corrections and the accordion geometry does not introduce extra contributions. The noise term (b/E) is compatible with measurements extracted from pedestal events. The position resolution in the two coordinates is:

$$\sigma_\eta = (0.210 \pm 0.015) \oplus \frac{4.70 \pm 0.05}{\sqrt{E}} mm \qquad (1)$$

$$\sigma_\phi = (0.186 \pm 0.021) \oplus \frac{3.87 \pm 0.05}{\sqrt{E}} mm \qquad (2)$$

The uniformity of the large scale prototype was measured with a beam of 287 GeV electrons shot over 123 spots. The resulting overall energy spectrum shows an rms of $(0.69 \pm 0.05)\%$ which is the global constant term. This is a convolution of the local constant term of 0.35% mentioned above and of another 0.58% (0.37% from calibration and 0.45% from mechanical non-uniformities) due to response variation over the large area.

3 Accordion Hadronic Barrel

The Accordion design was also used for the construction of a hadronic calorimeter prototype which was tested together with the em barrel prototype described in the previous section [4]. Two modules were tested, segmented longitudinally in two parts of 1.2 and 1.6 λ_I respectively. It consisted of 8×9 towers and its granularity was $\Delta\eta \times \Delta\phi = 0.045 \times 0.05$. The converter plates were made from stainless steel 9.8 mm thick and the LAr gap was 3 mm.

A novel technique was used for the readout, which was the EST (ElectroStatic Transformer) scheme. This signifies the fact that while ganging several LAr gaps to form a cell, a fraction of the gaps are connected in series. This is really helpful in reducing the resulting large detector capacitance, which is more critical here since the gaps are wider than the em case.

The pion data collected with beams of energies 20 to 400 GeV were analysed by applying a weighting method. The energy resolution found was:

$$\frac{\sigma_E}{E} = \frac{(51.6 \pm 2.6)\%}{\sqrt{E}} \oplus (3.3 \pm 0.1)\% \oplus \frac{2.5 \pm 0.1}{E} \qquad (3)$$

The measured uniformity over 4 cells was 1%.

4 Accordion EM Endcap

While the accordion design fits well radially the cylindrical barrel part, its use is not straightforward for the endcap, for which another setup had to be invented nicknamed Spanish Fan. The azimuthal symmetry is kept for the endcap and the accordion plates' waves are parallel to the vertex-pointing line. In the resulting design the zig-zag amplitude, the Lar gap and the absorber thickness are variable with the distance from the beam line so as to keep the sampling fraction constant with η [5]. A sketch can be seen in fig. 3. The full radius of the endcap in the actual experiment will be constructed in two parts. The prototype realised for tests is one sixth in azimuth of the inner endcap wheel and its rapidity coverage is $2.16 < |\eta| < 2.89$. Its granularity is $\Delta\eta \times \Delta\phi = 0.03 \times 0.05$ and is segmented in 3 samplings 9,9 and 7 X_0's deep. Due to the variable gap width along R the HV applied was also variable and different for every two η lines to keep the calorimeter response constant. The HV values were calculated by Monte-Carlo and the residual response variation was at the level of only a few percent.

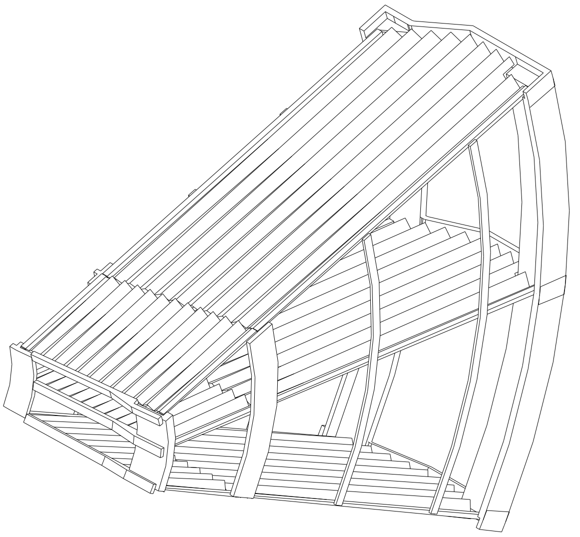

Figure 3: *The design of the accordion for the endcap.*

The energy resolution of the endcap prototype for different rapidity points is shown in figure 4. Its

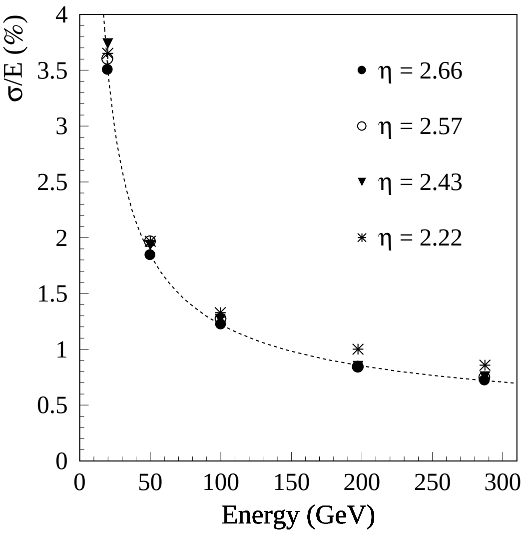

Figure 4: *Energy resolution obtained with the Spanish fan prototype.*

parametrisation for $\eta = 2.66$ is :

$$\frac{\sigma_E}{E} = \frac{(10.7 \pm 0.3)\%}{\sqrt{E}} \oplus (0.30 \pm 0.04)\% \oplus \frac{0.51 \pm 0.02}{E} \quad (4)$$

The uniformity of response over 48 cells gives a global constant term of $(0.79 \pm 0.04)\%$, shared almost equally by electronics (calibration, capacitance) and mechanical (ϕ modulation, gap, absorber thickness) non-uniformities. The position resolution of the prototype is measured to have a sampling term less than $5mm/\sqrt{E}$ and a constant term of around 0.25 mm. The performance is comparable with that of the barrel em prototype.

5 Preshowers

The calorimeter prototypes described above were developed following the requirements of the LHC physics guidelines, among which a light Higgs decaying to two gammas is a big challenge. To detect it one needs apart from very good energy resolution, good photon direction measurement and high γ/π^0 and γ/jet separation. To compensate the energy lost in the upstream material, measure accurately the shower position and reject π^0's the role of the em calorimeter has to be assisted by a preshower. The LARG community has adopted and tested two approaches for this purpose, a separate and an integrated preshower.

The **separate preshower** [6] is located in front of the calorimeter and it has two highly segmented layers with slanted strips, i.e. $\Delta\eta(\Delta\phi) = 2.5 \cdot 10^{-3}$, in ϕ and in η respectively. The first layer is after 2 X_0's of absorber material inside the em barrel cryostat and the second layer after one extra X_0 to increase photon conversion probability. The prototype covered the rapidity range between 0.2 and 0.8 and 9^o in azimuth. The 150 GeV muon signal was measured with a signal/noise ratio of 5.6 over 2 strips/layer (4 channels).

The energy resolution measured with the preshower-calorimeter system shows a sampling term of $(12.3 \pm 0.2)\%\sqrt{E}$. The position resolution in the two preshower layers is

$$\sigma_{\eta(\phi)} = 0.16(0.19) \oplus \frac{1.67(2.02)}{\sqrt{E}} mm. \quad (5)$$

The angular resolution measured by the preshower and the middle calorimeter layer is

$$\sigma_{\eta(\phi)} = 1.(1.) \oplus \frac{22.(27.)}{\sqrt{E}} mrad, \quad (6)$$

for electrons and for photons is shown in figure 5.

The **integrated preshower** [7] is actually realized by segmenting finely the first sampling of the calorimeter. This was achieved by drawing the strips of the kapton electrodes in a special way. The ones corresponding to the first sampling were oriented in two views, i.e. $u = \eta + \phi$ and $v = \eta - \phi$, and the ones of the two other samplings remained η oriented as they were in the em barrel module described in 2. Kaptons of u- and v-type where interleaved at stacking. The strip width of the first sampling was 5 mm and the effective granularity was $\Delta\eta \times \Delta\phi = 0.00441 \times 0.0784$. The longitudinal depths of the three samplings are 5.6, 14.6 and 9.1 X_0's respectively. The prototype covered rapidities from 0.4 to 0.9 and 9^o in azimuth. The sampling term of the energy resolution was found to be $(12.3 \pm 0.2)\%\sqrt{E}$. The position resolution of the first sampling is

$$\sigma_{\eta(\phi)} = 0.18(0.16) \oplus \frac{1.8(2.2)}{\sqrt{E}} mm. \quad (7)$$

The resolution of the angular measurement using one

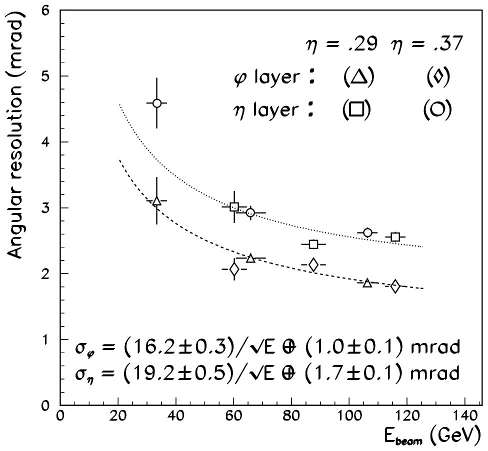

Figure 5: *Angular resolution for the separate preshower prototype, measured with photons.*

point in the 1st (u- and v-strips) and another one in the 2nd sampling is shown in figure 6 for electrons.

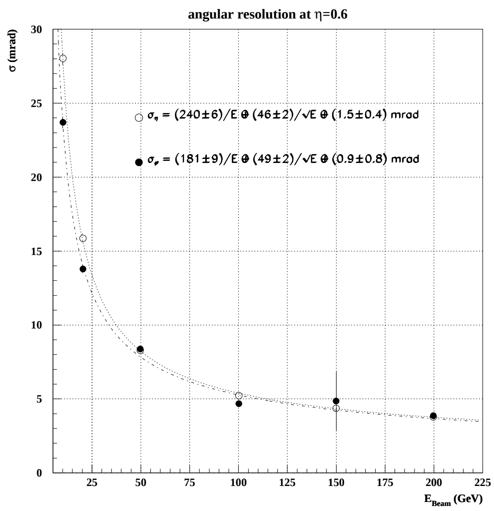

Figure 6: *Angular resolution for the integrated UV preshower prototype, measured with electrons.*

6 From Prototypes to ATLAS

The advances described above proved the capability of building large calorimeter systems with the Accordion principle. The ATLAS experiment has used these ideas to a large extent for the design of the detector.

The ATLAS calorimeter setup was defined based on the prototype results and the detailed simulations of the overall detector. The performance observed in the testbeam was preserved in the simulated calorimeter in ATLAS. After testing a lot of options for the calorimeter system [1] the collaboration adopted the solutions described below. For the barrel part of the em calorimeter the accordion design will be used with an integrated preshower, i.e. with a 1st sampling finely segmented in the η direction. To have the additional feature of correcting for the energy lost at the upstream material a single layer presampler will be used in front of the calorimeter. In the endcap region the spanish fan design will be implemented for the em part.

A first step towards ATLAS was the first testing with electron and pion beams of the system of the barrel em (Pb/LAr accordion) and hadronic calorimeter (Fe/Scintillator Tiles) prototypes. This combined test was successful in showing that the system of a liquid ionization em and a scintillator sandwich hadronic calorimeter is capable of reconstructing the energy of a hadronic shower with good energy resolution. More results on that are presented at the same conference (see talk by V.Boldea [8]). A preliminary analysis of 300 GeV pion data gave a resolution $\sigma/E = 4.1\%$.

Conclusions

The R&D on liquid ionization calorimetry combined with the Accordion technique has been very fruitful during the last few years with the realisation and tests of large scale prototypes. The achieved readout speed, granularity, radiation hardness, the energy and position resolution and the response uniformity are compatible with the LHC requirements. Those concepts have been adopted to the final design of the ATLAS detector.

References

[1] ATLAS Collaboration, Technical Proposal, CERN/LHCC/94-43.

[2] B. Aubert et al., NIM A309(1991)438,
B. Aubert et al., NIM A321(1992)467,
B. Aubert et al., NIM A325(1993)118.

[3] D.M. Gingrich et al., NIM A364(1995)290.

[4] D.M. Gingrich et al., NIM A355(1995)295.

[5] A. Chekhtman et al., ATLAS-CAL-NO-067 (1995).

[6] J. Collot, 5th Int.Conf. of Calorimetry in HEP, BNL 1994,
L. Drage, private communication.

[7] I. Wingerter-Seez, 5th Int.Conf. of Calorimetry in HEP, BNL 1994,
O. Linossier, private communication.

[8] V. Boldea, Four Seas Conf., Trieste 1995.