Progress report on the ATLAS liquid argon presampler

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on behalf of the ATLAS Collaboration,
by J.Y. Hostachy¹

*Institut des Sciences Nucléaires,
CNRS-IN2P3 and Université Joseph Fourier
53, Av. des Martyrs 38026, Grenoble Cedex, France*

Abstract

The electromagnetic calorimeter of the ATLAS experiment at the CERN Large Hadron Collider (LHC) will be of the accordion liquid argon (LAr) type. To achieve sufficient energy resolution it is necessary to correct for the energy loss upstream of the calorimeter. For this purpose a separate presampler detector, providing a shower sampling in a thin LAr layer (11 mm in depth) before the calorimeter, was developed by the ATLAS collaboration and tested at CERN in September 95. The combined response of this detector and a calorimeter prototype to muons and electrons is presented.

1 Introduction

The electromagnetic calorimeter of the ATLAS experiment at the CERN Large Hadron Collider (LHC) will be of the accordion liquid argon (LAr) type, a detector concept that has been developed by the RD3 collaboration [1] for use at LHC. To achieve a sufficient energy resolution it is necessary to correct for the energy lost upstream of the calorimeter. The corresponding amount of material is presently expected to be $1.3X_0$ at $\eta = 0$ and about $2.7X_0$ at $\eta = 1.3$. For this purpose a presampler detector, providing an energy sampling in a thin LAr layer (11 mm in depth) before the calorimeter, was developed. Its role would be even more crucial if, in the future, the amount of dead material had to be increased to cope with technical problems in the tracker or in the coil-cryostat system [2].

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¹E-mail: hostachy@isnhp2.in2p3.fr

The presampler design results from a simplified version of the preshower detector which was originally tested at CERN SPS [3] and then proposed in the Letter of Intent of the ATLAS detector [4]. A larger prototype of this preshower detector using 2 active layers, (each of them being preceded by a lead absorber plate) was built and successfully tested at CERN [5]. The presampler will have only one active layer without any extra absorber material in front [6]. Its design is not completely definite yet and some new improvements will be described in this paper.

2 Detector geometry: ATLAS design

Figure 1: Transverse cut of the ATLAS presampler detector.

As mentioned above, the presampler will be suspended in front of the accordion e.m. calorimeter, in liquid argon and therefore inside the barrel cryostat of the ATLAS detector. The modules are flat so that the ideal curved structure in ϕ was abandoned in favor of a polygonal one which is easier to build, see figure 1. The typical structure is composed of 32 identical azimuthal sectors ($\Delta\phi = 11.25^\circ$) of 3.1m length for half a barrel (pseudo-rapidity spread up to 1.5). Each azimuthal sector is composed of 8 modules of about 28 cm width. Their length increases in η from 28 cm up to 56 cm for the largest. These eight active modules are supported by 2 lateral thin skirts made with glassfiber-epoxy sliding on mini-rails anchored in front of the e.m. calorimeter. In total, 512 modules are needed to assemble the device.

3 The September 95 prototype

The September 95 prototype was composed of 2 modules covering 9 degrees in azimuth and a pseudo-rapidity range between $\eta = 0.48$ and $\eta = 0.80$. The modules, (see figure 2), were approximately 19 cm wide in azimuth and about 2x24 cm long in order to match the cells of the 2 m e.m. calorimeter prototype [1]. The depth of the active layer was reduced

to 10 mm instead of 11 mm as it will be in ATLAS. Each module read 64 elementary cells in the fine-grained direction (η) and 2 in the coarse one (ϕ). The granularity was $\Delta\phi \times \Delta\eta = 0.08 \times 0.0025$, and the total number of channels was equal to 256.

Figure 2: Exploded view of a module.

The modules were built with alternating anode and cathode electrodes defining the electrical field (~ 1 kV/mm) for the charge collection. The cathodes were double-sided copper clad glass epoxy circuits. The anodes had 3 copper layers insulated by 2 glass epoxy layers; the 2 outer copper layers were connected to a HV supply whereas the inner copper layer was read out by a preamplifier, see section 5. The overall thicknesses of those electrodes were $275 \mu\text{m}$ and $320 \mu\text{m}$ for the cathodes and anodes respectively. The electrodes were slanted in order to obtain a better space resolution via a barycenter calculation.

The amount of dead material in front of the prototype was equal to $0.83X_0$ at $\eta = 0.6$.

4 Module production technique

The modules were produced by moulding a layer of micro glass fiber-loaded epoxy on the top of the electrodes [5]. The electrodes were spaced and stacked by means of accurate shims in a hermetic mould. Such a technique allows to construct compact modules featuring an overall radial thickness of only 16 mm including electrical connections (ground, HV, signal pins).

5 Electronics

Figure 3: Preamplifier current noise as a function of the shaping time.

The anodes were read out directly in the liquid argon by monolithic GaAs preamplifiers working in a current-sensitive mode [7]. They were ion-implanted MESFET processes, and their power dissipation was 7.5 mW. The signal was filtered by a $CR\text{-}RC^2$ shaper located outside the cryostat with a shaping time of 20 ns. The equivalent noise current (ENI) at liquid nitrogen temperature is given in figure 3.

6 Optical links

Table 1: Some characteristics of the two optical link designs.

Emitting diodes	(driver) + Honeywell HFE4050 LED	Siemens STH51007G LD
λ	850 nm	1300 nm
power dissipation	≤ 20 mW	≤ 5 mW
Multimode step-index optical fibers (~ 10 m)	pure silica core + fluorine doped-silica cladding + polyimide coating 200/220/245 μm	HCR spectrum silica core and hard polyimide cladding 200/230/250 μm
PIN photodiodes	Si diodes	Indium-phosphide diodes
High speed, low noise ($\text{ENC} < 10pA/\sqrt{Hz}$) transimpedance amplifier		
Global features:		
number of channels	32	32
non-linearity	± 4 %	± 1 %
dynamic range	12 bits	15 bits

Signals from the front end preamplifiers were transferred out of the cryostat via either 12 channel flat cables (copper links) or analog optical links. The analog optical link readout [8] was based on either light emitting diodes (LED) or laser diodes (LD) placed in the liquid argon and coupled through fibers to PIN photodiodes located outside the cryostat at the receiving stage. Some particular points of the two optical designs are presented in table 1. This technique was studied for compactness reasons. Feedthroughs with a density of 10 optical fibers per mm^2 were built and successfully tested [8].

7 Performance in a test beam

The test was performed on the H8 beam line of the CERN SPS in September 95 with electrons. Muon data were also collected by exploiting the large μ contamination in the electron beam around 150 GeV/c. The beam line was equipped with four fast scintillation counters, used in the trigger, and three drift chambers which allowed to extrapolate the particle impact point in the presampler.

7.1 Response to muons

Figure 4: Muon signal read out by GaAs preamplifiers.

The muon signal was reconstructed by adding the contributions of two adjacent cells: the most energetic one and its most energetic neighbor found in a window of 5 cells centered on the extrapolated beam impact point. This signal is plotted on figure 4. The signal/noise ratio is 4.8, in good agreement with what was expected.

The position of the incident muon was determined using a barycentric calculation within a cell cluster. The resulting distribution of the beam particle is periodic because of the discrete structure of the detector (period of one cell). In figure 5 the profile of the η impact position using the beam chambers is plotted as a function of the position measured by the presampler. Such a modulation can be corrected using a S-shape function²:

$$\begin{aligned} \eta_{TRUE} = & a_0 + a_1 \cdot \text{round}(\eta_{PS}) \\ & + a_2 \cdot (\text{round}(\eta_{PS}))^2 \\ & + a_3 \cdot \tan^{-1}[a_4 \cdot (\eta_{PS} - \text{round}(\eta_{PS}))] \end{aligned}$$

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²round(x) $\equiv$ closest integer to x

Figure 5: Profile of the impact position given by the beam chambers against the position found using the presampler. The fitted correction function is superimposed.

where the last term describes the pattern and the first three give the global position (practically along a straight line).

The space resolution for 150 GeV muons at $\eta = 0.59$ after S-shape correction was equal to 870 μm .

7.2 Response to electrons

7.2.1 Energy resolution

The electron signal was collected over 7 presampler cells in η centered on the most energetic channel. The total energy was calculated from the following relation: $E_{tot} = \lambda(\alpha E_{ps} + \beta E_1 + E_2 + \delta E_3)$, where E_{ps} , E_1 , E_2 , E_3 refer to the signals collected in the presampler and the three calorimeter radial compartments, α , β and δ are weights introduced to minimize the width of the energy distribution and λ is an overall calibration coefficient. Standard position-dependent energy corrections were applied to the calorimeter in order to correct for the shower containment in η and the modulation of the transverse LAr thickness in ϕ [1]. Figure 6 shows the energy resolutions obtained with the copper and the optical links. They are very close showing the possibility of using the optical fiber technology.

Figure 6: Energy resolution as a function of the incident electron energy measured with copper links ($\eta = 0.59$) and optical links ($\eta = 0.63$).

7.2.2 Detector linearity

The linearity has been estimated by comparing the average energy of the presampler-calorimeter system, after energy correction and absolute calibration at 200 GeV, with the nominal energy of the beam, see figure 7. In this picture, the two dotted curves represent the uncertainties on the beam momentum, i.e.:

$$\frac{\Delta P}{P} = \frac{25\%}{P} \oplus 0.5\% \quad (P \text{ in GeV})$$

where the first term is linked to the hysteresis effect of the bending magnet and the second term includes the uncertainties due to geometry and calibration.

Figure 7: Linearity in energy of the presampler-calorimeter response to electrons. The two dotted curves represent the uncertainties on the beam momentum, see text.

7.2.3 Space resolution

The electromagnetic shower positions were reconstructed as the energy-weighted barycenter of the three adjacent cells consisting of the most energetic one and its two neighbors. The positions were also provided by means of the 3 beam chambers. The space resolution at $\eta = 0.59$ as a function of the incident electron energy, after S-shape correction and after unfolding the contribution due to the beam chambers, is given in figure 8. For energies larger than 100 GeV the space resolution is better than $700 \mu\text{m}$. This space resolution strongly depends on the number of radiation lengths in front of the presampler. It is better where the amount of dead material is larger [5].

Figure 8: Space resolution of the presampler after S-shape correction and unfolding of the beam chamber contribution.

8 Conclusion

The moulding procedure developed over the last three years to produce presampler modules is technologically a good solution for larger scale construction. The performance of the prototype tested in electron and muon beams shows that the presampler can adequately fulfill its role. Nevertheless the ATLAS collaboration has recently decided that the final presampler will have its electronics located outside the cryostat and its number of channels reduced. The new granularity ($\Delta\phi \times \Delta\eta = 0.1 \times 0.025$) will be obtained by grouping several elementary cells together. The number of independent channels will be about 8,000 instead of 64,000. In parallel, a new production technique has been developed where the electrodes will be glued on both sides of FR4 plates by means of prepreg (i.e. pre-impregnated foils). This technique has some advantages: the resulting modules are lighter (half the weight, ~ 1.5 kg), the production is quicker, no hard cleaning process is requested for the mould, simpler equipment is required. This second module production technique is most likely to be used in the future.

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