CONSTRUCTION AND TEST OF A FINE-GRAINED LIQUID ARGON PRESHOWER PROTOTYPE

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on behalf of the RD3 Collaboration,
by Johann COLLOT
Institut des Sciences Nucléaires
CNRS-IN2P3-Joseph Fourier University
53,Av. des Martyrs 38026 Grenoble France
e-mail:collot@frcpn11.in2p3.fr

ABSTRACT

Over the last two years, the RD3 collaboration has been studying a separate LAr preshower consisting of two layers featuring a fine granularity of 2.5 10^{-3}. A prototype covering approximately 0.8 in pseudo-rapidity and 9° in azimuth was built and tested at CERN in July 94. It has a modular structure which is appropriate for a much larger scale construction. Its modules were produced using a moulding technique developed for this application. CMOS and GaAs VLSI preamplifiers were also designed and tested for this occasion. Preliminary test beam results are presented.

1. Introduction

The idea of equipping the accordion LAr electromagnetic calorimeter, designed for the future large hadron collider of CERN, with a fine-grained preshower detector is dictated by several arguments. A device is needed to independently measure the energy lost in the inactive material upstream of the calorimeter, thereby preserving the energy resolution of electron and photon signals. By combining the position measurements of the first calorimeter compartment and of the preshower, a precise determination of the particle direction can be derived which helps in keeping the two photon invariant mass resolution within a tolerable range to observe the $H \rightarrow \gamma\gamma$ decay mode. Furthermore it was demonstrated in previous analyses that a jet rejection factor of 10^4 is mandatory to reduce the huge background contribution stemming from γ-jet QCD events below the $H \rightarrow \gamma\gamma$ signal. This implies a rejection factor better than 3 of the preshower-calorimeter system against isolated π_0's arising from parton fragmentation fluctuations.

The potential of a fine-grained preshower with at least 3 X_0 of material to convert photons in front of its second layer measuring the longitudinal position was explored with a small prototype (6×6 cm^2) at CERN a few years ago [1] . The obtained performance showed the adequacy of the concept regarding the LHC requirements . Here we present the study of a modular system that constitutes a step forward in the integration of such a preshower into the ATLAS calorimetry system. Some other details may be found in [2].

2. Detector geometry

At the scale of ATLAS such a detector would exhibit a polygonal structure formed by assembling 32 identical sectors of 2.7 m each, covering half a barrel (pseudo-rapidity spread: 1.4). These sectors would be suspended on mini-rails anchored in front of the electromagnetic calorimeter. Such an assembly concept would allow one to slide in and out the preshower sectors during the initial mounting phase or any exceptional maintenance operations without moving the electromagnetic calorimeter out of its cryostat.

The transverse cut of a preshower sector prototype featuring an azimuthal angle of 9° is presented in figure 1.

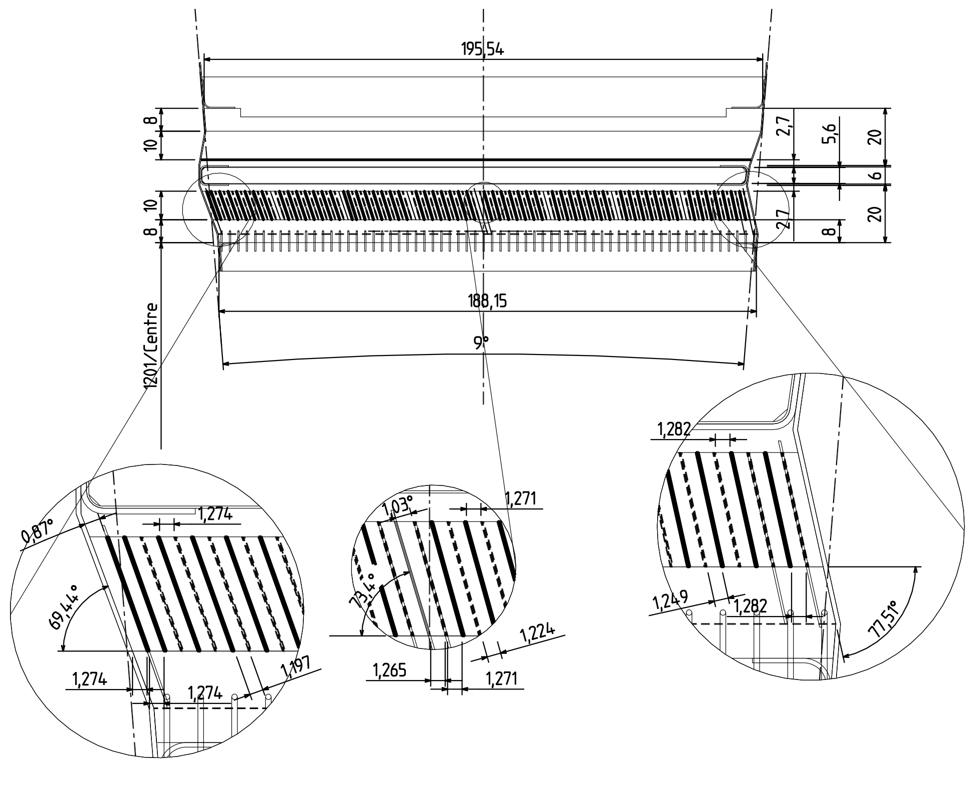

Figure 1: Transverse cut of the preshower prototype

Ten modules arranged in two layers reading the ϕ and η coordinates and sandwiching an internal lead converter plate, are supported by two lateral thin skirts made with stainless steel. The granularity of the active layers in the fine-grained dimension is $\Delta\phi$ or $\Delta\eta$=2.5 10^{-3} and is kept constant over the entire structure. The length of the ϕ strips is constant and fixed to 110 mm. In the η layer , this length is 94 mm representing half of the sector opening. The liquid argon gap varies from 1.2 mm in the ϕ cells to 1.6 mm for the last η module.The strips are slanted so that they offer a 100% geometric efficiency to muons and improve the space resolution. The internal lead layer adds one more radiation length in front of the second active sampling, while an external lead plate fixed on the skirts complements the amount of material to a constant thickness of 2 X_0 before the ϕ active layer. They are both tapered in the longitudinal direction to keep the amount of material constant in front of their respective sampling.

A preshower module reads 64 elementary intervals in the fine-grained direction and 2 in the coarse one; therefore there are 128 individual cells on each module. Seven modules - 4 in the ϕ direction and 3 in the η one - were mounted and tested at CERN in front of the accordion 2m prototype [5] in July 94. They approximately covered a pseudo-rapidity range of 0.2 to 0.8 .

3. Module production technique

A preshower module is produced by moulding a layer of epoxy on top of the strips stacked in a hermetic mould and precisely positioned by spacing shims. The cathodes are made with Cu-Be and are 0.2 mm thick. The anodes are multi-layer kapton electrodes with Cu-clad HV pads on their external faces. They are .25 mm thick on average. Numerous tests were performed to select the epoxy system and the composite structure in order to obtain a correct cryogenic behavior of the modules. The epoxy resin finally selected (CIBA - GEIGY system MY745, HY905, DY072) is loaded using micro glass fibers (50% in weight). Its relative shrinkage coefficient from room temperature to LN_2 temperature after loading is $\Delta L/L = 0.7$ %. Moreover, to obtain an object remaining flat when cooled down to LN_2 temperature, we had to insert glass-epoxy reinforcement bars buried in the epoxy resin. Some of them are placed along the lateral edges, the others are laid down in the x and y directions; they further reduce the shrinkage coefficient of the composite object down to a value comparable to the glass epoxy one. The resin is injected with the mould placed in a vacuum-oven. A differential pressure of 0.3 bar is applied during the injection. The polymerization cycle lasts 16 h and reaches 130 °C. After unmoulding and ethanol cleaning, NOMEX honeycomb strips are slid into the cells to safely maintain the liquid argon gap.

4. Electronics

Given the high channel density of such a detector, VLSI techniques have to be employed to design the front-end electronics. This work has started by devising and producing octal preamplifier chips in CMOS and GaAs monolithic processes.

4.1. CMOS preamplifiers

ICON is a current conveyer preamplifier based on a layout that was originally considered for the readout of silicon detectors [3]. To meet the particular needs of the LAr calorimetry, some improvements had to be made regarding the current gain and the noise. This study was carried out using CMOS monolithic processes of three different firms: MIETEC, ES2 and AMS. So far the best performance with respect to the speed was measured at 77 °K on the AMS 1.2 μm version (t_p(260 ns triangle)=50 ns and 60 ns when filtered by a CR-RC^2 filter of 50 ns shaping time), while the equivalent noise current was found at 19 nA for a CR-RC^2 shaping time of 50 ns. Because of the lack of time, 512 channels of the MIETEC version, which has a lower performance in terms of speed (t_p(260 ns triangle)=80 ns and equivalent noise current=9 nA), were utilized to equip 4 preshower modules in July 94. Their outputs were integrated by 40 ns gated integrators and subsequently digitized by 12-bits ADC's.

4.2. GaAs preamplifiers

The second readout device under study is a monolithic charge-sensitive preamplifier made with a GaAs ion-implanted MESFET process [4] . The chip developed contains dominant pole preamplifiers with a gain-bandwidth product of about 1 GHz. The preamplifier input capacitance is 12 pF. The series noise at 87°K is 0.54 nV/$\sqrt{Hz}$ and the corner frequency of the 1/f noise does not reach 1 MHz. Its power dissipation is 7.5 mW. With CR^2-RC^2 bipolar shaping an ENC of 436 + 21 e^-/pF at 28 ns was measured at 87°K. 384 channels of that type were mounted on 3 preshower modules for the July 94 test beam period. Their outputs were filtered through 50 ns CR^2-RC^2 shapers, and then sent to 12-bit ADC's.

5. Performance in a test beam

The results presented in this paragraph are from the analysis of the data collected at CERN in July and August 94 in a test beam of electrons and photons. Because of limited time, no effort has so far been devoted to ameliorate the precision of the energy calibration coefficients of the preshower channels that were determined on-line with an accuracy of about ±15%. However as the average fraction of the electron energy deposited upstream of the calorimeter does not exceed 6% at high energy (≥287 GeV), this has limited effect on the energy resolution of the preshower-calorimeter system. As an example, the energy deposited by 287 GeV electrons is presented in figure 2. The electron signal was cumulated over a calorimeter cell nonet and 100 (50/layer) cells in the preshower centered on the most energetic channel. The represented quantity is the total energy obtained as $E_{tot} = a(\alpha E_{psh}+\beta E_1+ E_2+E_3)$, where E_{psh},E_1,E_2,E_3 refer to the energy collected in the preshower and the three calorimeter radial compartments; α,β are energy dependent weights introduced to minimize the width of the energy distribution; a is an overall calibration coefficient. The standard position-dependent energy corrections were applied to correct for the shower containment in η and the modulation of the transverse LAr thickness in ϕ [5].

The signal from 150 GeV muons as reconstructed in 4 (2/layer) preshower strips equipped with CMOS preamplifiers, was measured with a signal/noise ratio of 5.6, that is 9 nA of current noise per channel in very good agreement with the value quoted in section 4.1.

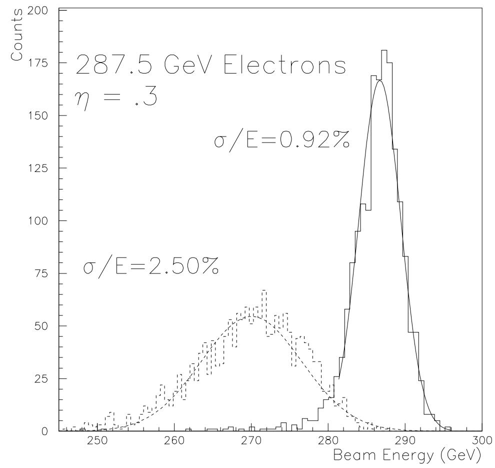

Figure 2: Energy reconstructed in the preshower-calorimeter system from 287 GeV e^- before and after adding the preshower contribution

The electron shower position in each view is obtained by calculating the energy-weighted barycentre of a triplet of cells centered on the channel with the largest signal. From the comparison of this reconstructed position to the one extrapolated from 3 beam chambers located upstream of the cryostat, a typical s-shape correction was fitted and used to correct the barycentre for a bias in the vicinity of the cell center. Figure 3 shows the position resolution obtained in both views as a function of the incident electron energy after s-shape correction and unfolding of the beam chamber contribution (σ = 250-300 μm).

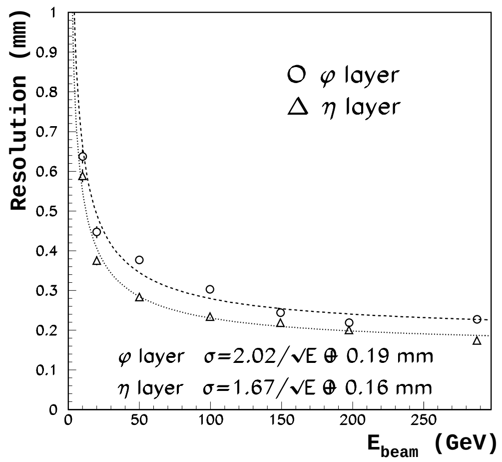

Figure 3: Space resolution of the preshower after s-shape correction and unfolding of the beam chamber contribution

The curves which are superimposed on the data points agree very well with the predictions of some Monte-Carlo simulations: σ_ϕ=1.83 mm/ $\sqrt{E(\mathrm{GeV})}\oplus$ 0.24 mm ; σ_η=1.72 mm/ $\sqrt{E(\mathrm{GeV})}\oplus$ 0.19 mm. The space resolution is slightly better in the η layer where the signal is bigger owing to the additional lead placed in front. Above 200 GeV, the position resolution is better than 220 μm in both views.

6. Conclusion

The moulding process developed over the last two years to produce preshower modules is technologically a good candidate for larger scale construction. Its industrialization is now under way. The performance of the prototype measured in an electron test beam shows that this concept meets the LHC requirements especially with respect to the space resolution. Although GaAs cold analog electronics seem more promising for this application, CMOS preamplifiers may constitute a good alternative solution if their resistance to ionizing radiation can be achieved. The difficulty of the integration of such a device in a detector such as ATLAS comes from the huge number of electronic channels (120,000 for $|\eta| \leq$1.4) to bring out of the cryostat. Analog optical links [6] that allow the reduction of the overall diameter of the cryostat feedthroughs, may be envisaged.

7. Acknowledgements

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8. References

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