ATLAS BARREL HADRON CALORIMETER
THE MODULE 0 EXPERIENCE

I.Efthymiopoulos
CERN
PPE Division
1211 Geneve 23, SWITZERLAND

representing the ATLAS/Tile Calorimeter Collaboration

The ATLAS hadronic barrel calorimeter is an iron-scintillating tile calorimeter with an innovative geometry, rather appropriate for the construction of large volume detectors such as the ATLAS experiment at LHC. In the last two years the Tile Calorimeter collaboration has passed from the testing of calorimeter prototypes to the construction of real size modules. One module for the barrel and two for the extended barrel calorimeters have been constructed and tested with beam. Highlights of this effort and performance results obtained from the test beam are presented here.

1 Introduction

The Tile Calorimeter is designed as the Barrel and Extended Barrel Hadron Calorimeter of the ATLAS experiment at LHC, placed behind the em Liquid Argon (LAr) calorimeter[1]. The detector consists of a cylindrical structure with inner (outer) radius of 2280(4230)mm. The barrel part is 5640mm in length along the beam axis, while each of the extended barrel cylinders is 2910mm long. The calorimeter covers the region from $|\eta| < 1.0 (0.8 < |\eta| < 1.7)$ in the barrel(ext. barrel) part. Each cylinder is built of 64 independent wedges (modules) in the azimuth direction. Within its volume once assembled, all the sub-detectors of the experiment, except from the muon system, will be placed. The massive iron structure should be rigid enough to support their weight, with the most important components being the full LAr cryostat with the solenoid.

The thickness of the calorimeter ($\sim 10\lambda$ at $\eta = 0$) is chosen such that the hadronic showers are well contained and that there is enough material to reduce the particle flux to the muon system. In addition, the ability to identify muons will help to recover the momentum resolution for the low energy muons where the energy losses tend to dominate.

The principle of the calorimeter

The calorimeter is an iron-scintillating tile sampling calorimeter, in which, contrary to what is usual up to now, the tiles instead of being placed

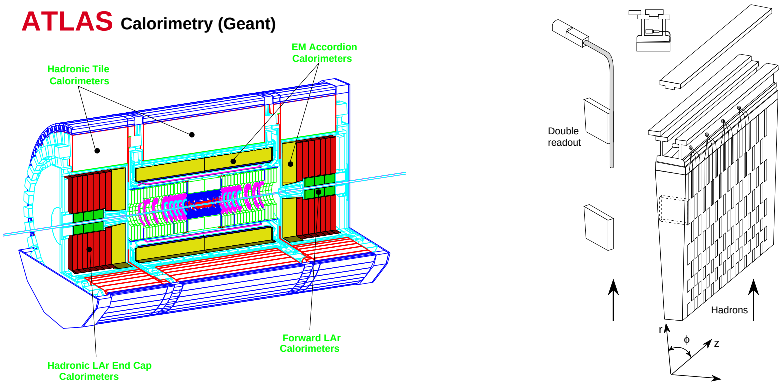

Figure 1: Left: View of the ATLAS calorimeter systems. Right: The principle of the Tile Calorimeter.

perpendicularly to the incoming particles, they are placed radially and staggered in depth [2]. For the light readout two WLS fibers are used, which run across each side of the calorimeter modules. The fibers from each side of each readout cell are grouped together in bundles and are read out by one PMT, thus giving enough light yield and providing useful redundancy. All the FE electronics are designed in a rather compact form and are placed in the outer radius of the detector placed inside a strong iron structure, which also provides the necessary shielding for the magnetic field.
From 1993 up to 1996, five prototype modules were built in total, corresponding to different stages in the R&D work. They were tested in both standalone and combined mode with the em barrel calorimeter prototype in front. The poin energy resolutions obtained are parameterized as:

$$\frac{\Delta E}{E} = \frac{(46.7 \pm 1.1)\%}{\sqrt{E}} + (2.2 \pm 1.2)\% \qquad (1)$$

$$\frac{\Delta E}{E} = (\frac{(38.3 \pm 4.6)\%}{\sqrt{E}} + (1.6 \pm 0.3)\%) + \frac{(3.0 \pm 0.2)\%}{E} \qquad (2)$$

for the standalone and the combined run respectively, matching well the physics requirements in ATLAS [3] [4].

2 The Module 0 construction

One of the big advantages in the design of the calorimeter is that the whole mechanical assembly can be done completely independent from the optical instrumentation. In addition, the periodic structure of the calorimeter allows the construction of large modules such as the ones need to be built for ATLAS. The basic geometrical element is a **period**, which consists of two *master plates* (large trapezoids) 5mm thick, and two sets of *spacer plates* (small trapezoids) 4mm in thickness. The spacer plates are placed between the master plates such that to leave empty pockets where later on the 3mm thick scintillator tiles are put.

The detector mechanics

Each of the barrel(ext. barrel) module consists of 19(10) **sub-modules**, each separated by a design gap of 0.8mm, mounted on a strong back support **girder**, which also houses the readout electronics. The very modular design of the calorimeter allows the construction of the various sub-modules (in total 2535 sub-modules, each weighting about 900Kg) to be done independently in various participating laboratories, using minimal manpower and tooling. Each sub-module is a stack of steel plates of different sizes (masters and spacers) typically forming 16 periods, bonded together with a structural adhesive and welded with straps at the four corners. For the Module 0 prototypes 42 sub-modules in total were constructed at 7 different laboratories, spread between Europe and USA. The final assembly for the modules was done in the three **regional centers**: the JINR,Dubna for the barrel, and the IFAE/Barcelona, ANL/USA for the two extended barrel modules.

Once the modules have been assembled, the optic components (scintillators and WLS fibers) were installed. The whole procedure is rather simple and time effective. The tiles (wrapped already at the production site) are inserted into the pockets left in the absorber volume, and then the fibers housed in plastic profiles (3 or 4 in each) are inserted into the small grooves left at each side of the module along the tiles and the spacers. Finally the fibers are grouped together in bundles at the outer radius of the detector and then glued at predefined positions in the girder structure. As a last step the fiber bundles are polished, and the drawer containing all the PMTs and the readout electronics is inserted into the girder. A full control of the module is performed using a scan with a ^{137}Cs radioactive source before is shipped to CERN, ready to be installed in the test beam.

The detector electronics

All the PMTs and the read-out electronics of the calorimeter are positioned in drawers which are inserted into the girder structure. The photomultipliers used in the Module 0 prototypes are of the Hamamatsu R5900 series with 10 or 8 stages. They show quite good performance with low voltage ($\sim 660V$) at the nominal 10^5 gain, and rather good linearity and low dark current

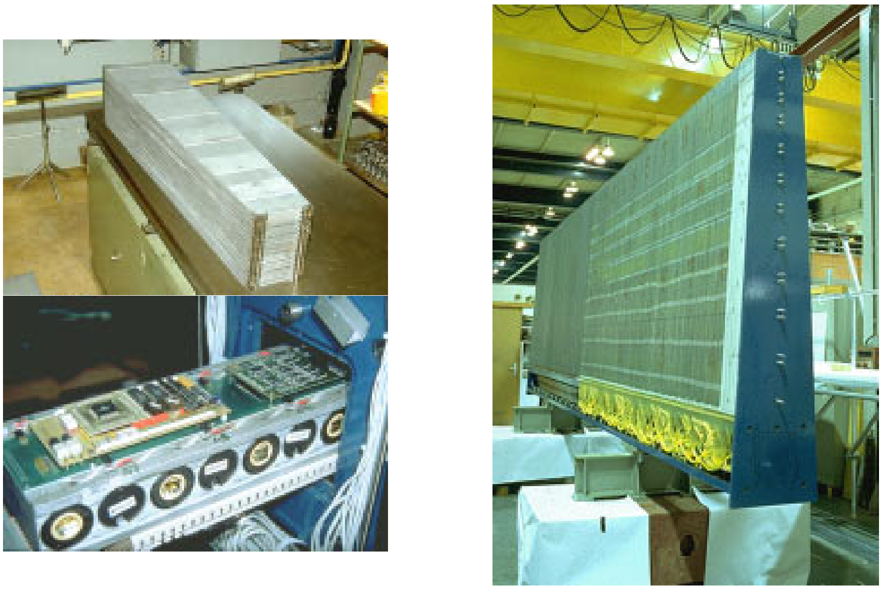

Figure 2: Left: (top) An assembled sub-module. (bottom) A complete drawer ready for installation in the detector. Right: The barrel Module 0 after assembly and instrumentation.

($< 100pA$). In addition, they are quite compact (length 20mm) with sufficient area (useful photocathod $324mm^2$). A new generation of the same PMTs with improved characteristics (quantum efficiency) is currently under tets, along with other candidate tubes. The final decision will be reached by the end of 1998.

The PMT signals are fed to a unipolar shaper (FWHM $\sim 50ns$) and then to a compressor circuit, needed in order to cover the dynamic range (16 bits) required for ATLAS using a 10 or 12 bit ADC module. In the past, two solutions were tested for the compressor: the first one with a circuit with piece-wise linear compression curve[5], and the second with a bi-gain system. Based on performance, cost and convenience in operation arguments, the bi-gain system solution was selected for the final electronics. In addition to the fast electronics a current integrator is included which reads directly the PMT signal for the reading of the ^{137}Cs source response during the calibration. All the front end electronics (shaper, compressor, integrator) are put in the same board, the **3in1 card**, mounted behind the PMT in the **PMT block**. For the tests with the Module 0 prototypes the digitizer system was placed outside of the detector in a VME create, while in ATLAS all the digitization and trigger sum electronics will be placed into the drawers as well. A prototype of the complete digitizer system as is scheduled for the 1998 test beam.

3 Performance results

In 1996 the barrel Module 0 and in 1997 the two extended barrel Module 0's were tested in the H8 beam line at the CERN SPS. Since the Module 0 prototypes are not enough to have sufficient containment of the hadronic showers, the old 1m prototypes were placed at the bottom and on the top in order to form a stack of 0.3rad in azimuth, as shown in Figure 3
The modules have 3 segments in depth, corresponding to 1.37, 3.87, 1.76 (1.37, 2.48, 3.14) interaction lengths at $\eta = 0$ in the case of the barrel (extended barrel). The cell geometry is defined such that to be semi-projective as in ATLAS. The energy resolution has been studied in the energy range from 10 to 400 GeV and at various angles, simulating particles arriving from the interaction point. Uniformity of response to both pions and muons in theta, phi and z has been studied as well.

Resolution and linearity

The energy spectra are directly obtained from the raw data, just adding the charge measured in each cell and calibrated in the electron scale. The spectra are rather symmetric, with the presence of small low energy tails due to longitudinal and/or transversal leakage and some high energy tail due to problems in the electronics and due to the $e/h > 1$. The peak and σ values are obtained from the raw spectra without leakage corrections doing a Gaussian fit over the $\pm 2\sigma$ range. For the barrel module at $\eta = 0.35$, the energy dependence of the resolution is well fitted by a linear sum of a sampling and a constant term :

$$\frac{\Delta E}{E} = \frac{(46.7 \pm 1.1)\%}{\sqrt{E}} + (2.2 \pm 1.2)\% \tag{3}$$

with similar performance shown for the ext. barrel modules. Fitting the pion response linearity of the calorimeter assuming a logarithmic increase in the fraction of the electromagnetic energy, the e/h is measured to be 1.40 ± 0.07, well in agreement with the 1m prototypes.

Uniformity

The uniformity of the calorimeter in both the azimuth and in η has been studied with 100 GeV pions. The response across η, shown in Figure 4(left), is quite uniform a dispersion within 2% at the part of the calorimeter that is

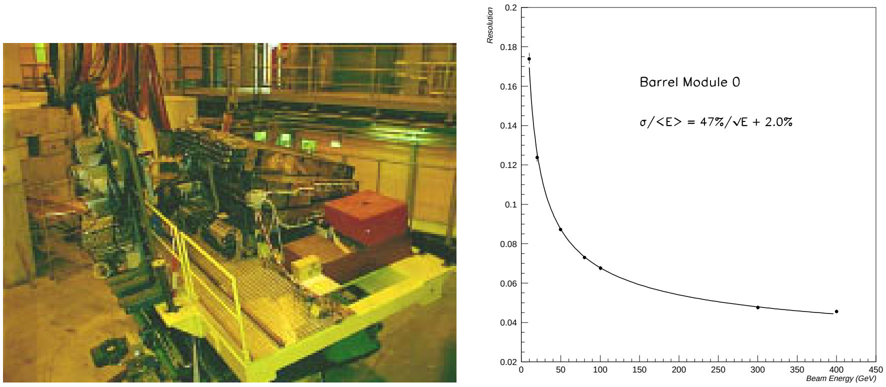

Figure 3: Left: The 1997 test beam setup with the two extended barrel Module 0's. Right: The energy resolution for pions as a function of the beam energy from the barrel Module 0 data.

not affected by lateral leakage. In Figure 4(right), the data from the ϕ scan which spans the full face of the calorimeter are shown. Each data point is taken from the energy spectrum fit and they are normalized to the point at the center of the Module. This scan can test if there is extra light produced at the fibers or the crack between modules. No such an effect is observed here and the whole response stays constant to a few percent level.

Response to muons

The ability of the calorimeter to identify muons passing from its volume was tested using muon beams at various energies. In Figure 4(right) the energy spectrum when 100 GeV muons incident at $\eta = 0.55$ is shown, fitted to a Landau function convoluted with a Gaussian. The pedestal distribution (random triggers) is also shown where a clear separation is observed.

Leakage studies

To study the longitudinal leakage in the calorimeter, a set of scintillators was placed at the back and at the side of the detector. In Figure 5(left) the punchthrough probability (defined as the fraction of events with a signal in at least one of the counters) is shown (corrected for the acceptance) as a function of the beam energy. Results from the standalone runs and from the combined run with the LAr em calorimeter in front are shown as well. In the standalone case at 100 GeV the probability is about 22%, while in the combined case drops to 15%. In Figure 5(right) the average energy loss (defined as the difference between the energy mean values of events with and without a signal in the counters) from leakage is shown for various beam

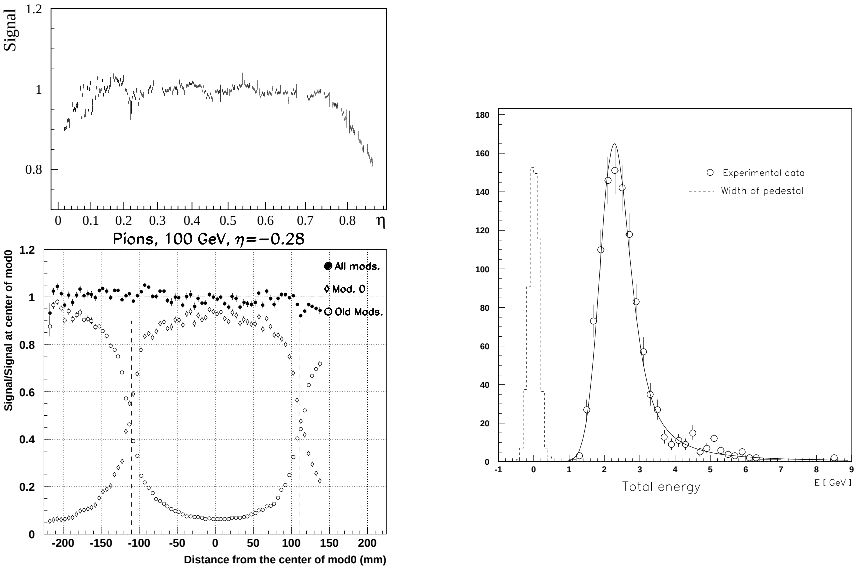

Figure 4: Left: (top) The calorimeter response for 100 GeV pions over the whole eta range. The drop at each side is due to the lack of containment. (bottom) The response uniformity to 100 GeV pions scanning the full calorimeter along the azimuth direction. Right:The energy spectrum from 100 GeV muons at eta=0.55.

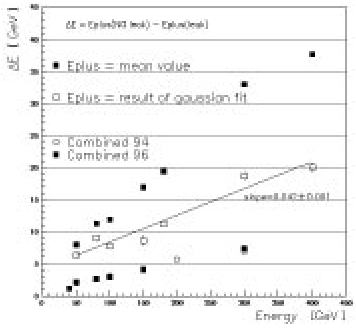

Figure 5: Left: The punchtrhough probability for pions. Right: Average energy loss vs. beam energy for events with longitudinal leakage.

energies. For 300 GeV the energy loss is about 18GeV (6%) which drops to about 2.3% in the combined case.

4 Conclusion

In the last two years the collaboration has moved from the prototype work to building real ATLAS modules (Module 0's) for both the barrel and the extended barrel parts. The construction of these modules was done following the proposed scenario for the series production of modules. Substantial experience has been gained in all the aspects of the module construction. The modules constructed were tested in the beam, and the analysis of the data is in progress. The first results obtained so far indicate a similar performance to that of the prototypes which meets the requirements set for ATLAS. After the submission of the detector TDR, the green light for construction has been given, nevertheless there are still few ongoing R&D projects (optics, PMTs, electronics) that are scheduled to come to conclusions by the end of 1998. The collaboration feels confident that the task of building this huge detector will be accomplished despite the large effort required in the next years to have it ready in time.

References

1. Tile Calorimeter Techinical Proposal, CERN/LHCC 96-42, 15 December 1996
2. F.Ariztizabal *et al.* (RD34 Collaboration), *Nucl. Instrum. Methods* A **349**, 384 (1994)
3. Construction and Performance of an Iron-Scintillator Hadron Calorimeter with Longitudinal Tile Configuration. RD34 Collaboration, CERN/LHCC 95-44, LRDB status report/RD34, 1995
4. Z. Ajaltouni *et al.* (ATLAS Collaboration), *Nucl. Instrum. Methods* A **387**, 333 (1997)
5. J.A.Perlas *et al.*, ATLAS Internal Note, TileCal-No-116 (1997)