STATUS OF ATLAS TILE CALORIMETER AND STUDY OF MUON INTERACTIONS

L. E. PRICE

Bldg 362, Argonne National Laboratory, Argonne, IL 60439, USA
E-mail: lprice@anl.gov

(For the ATLAS Tile Calorimeter Collaboration)

In this paper, we provide a description and status report on the barrel hadronic calorimeter for the ATLAS detector at the CERN Large Hadron Collider. We describe measurements taken with prototype and initial modules of the calorimeter, in particular those involving muon energy loss.

1 Brief Description of the ATLAS Tile Calorimeter

The ATLAS [1] Tile Calorimeter [2] is a sampling device made out of steel and scintillating tiles, as absorber and active material respectively. It realizes a simple and very well proven idea of calorimetry, particularly suited for the LHC environment. The absorber structure is a laminate of steel plates of various dimensions, connected to a massive structural element referred to as a girder. The highly periodic structure of the system allows the construction of a large detector by assembling smaller sub-modules together. Since the mechanical assembly is completely independent from the optical instrumentation, the design becomes simple and cost effective. Simplicity has been the guideline for the light collection scheme used as well: fibers are coupled radially to the tiles along the outside faces of each module. The laminated structure of the absorber allows for channels in which the fibers run. The use of fiber readout allows the definition of a three-dimensional cell read-out, creating a pseudo-projective geometry for triggering and energy reconstruction. A compact electronics read-out is housed in the girder of each module. Finally, the read-out of the two sides of each of the scintillating tiles into two separate photon detectors (in our case photomultipliers, PMTs) guarantees a sufficient light yield and provides a redundancy which might be needed during the long expected period of operation of the ATLAS experiment.

A conceptual design of this calorimeter geometry is shown in Figure 1. The absorber structure is a laminate of steel plates of various dimensions stacked along Z. The basic geometrical element of the stack is termed a period. It consists of a set of two master plates (large trapezoidal steel plates, 5 mm thick, spanning along the entire X dimension) and one set of spacer plates (small trapezoidal steel plates, 4 mm thick, 10 cm wide along X). During construction, half-period elements are preassembled starting from an individual master plate and the corresponding 9 spacer plates. The relative position of the spacer plates in the two half periods is staggered in the X direction, to provide pockets in the structure for the subsequent insertion of the scintillating tiles. Each complete stack, called a module, spans $2\pi/64$ in the azimuthal angle

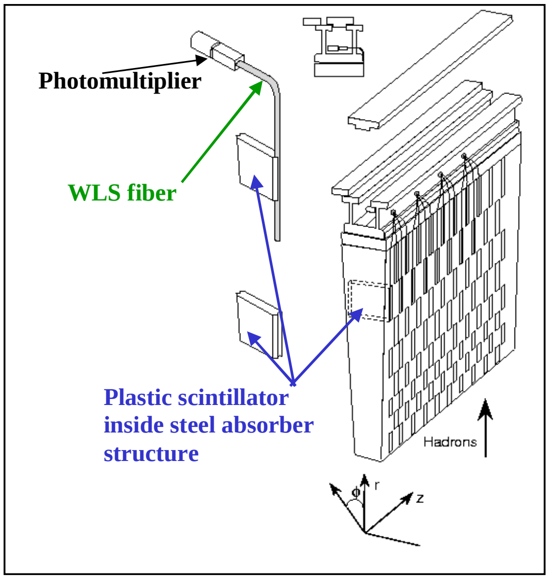

Figure 1. Conceptual layout of ATLAS Tile Calorimeter

(Y dimension), 100 cm in the Z direction and 180 cm in the X direction (about 9 interaction lengths, λ_I, or about 80 effective radiation lengths, X_0). Each module has 57 repeated periods. The module front face, exposed to the beam particles, covers 100×20 cm^2. The scintillating tiles are made out of polystyrene material of thickness 3 mm, doped with scintillator. The iron to scintillator ratio is 4.67 : 1 by volume. The calorimeter thickness along the beam direction at the incidence angle of $\Theta = 10$ deg. (the angle between the incident particle direction and the normal to the calorimeter front face) corresponds to 1.49 m of iron equivalent length [9].

Wavelength shifting fibers collect the scintillation light from the tiles at both of their open (azimuthal) edges and bring it to photo-multipliers (PMTs) at the periphery of the calorimeter (Fig. 1). Each PMT views a specific group of tiles through the corresponding bundle of fibers. The modules are divided into five segments along Z and they are also longitudinally segmented (along X) into four depth segments. The readout cells have a lateral dimension of 200 mm along Z, and longitudinal dimensions of 300, 400, 500, 600 mm for depth segments 1 – 4, corresponding to 1.5, 2, 2.5 and 3 λ_I at $\Theta = 0$ deg. respectively. Along Y, the cell sizes vary between about 200 and 370 mm depending on the X coordinate.

2 Calorimeter Fabrication and Status

2.1 Mechanics

The full Tile Calorimeter consists of a barrel cylinder centered at Z=0 which is 564 cm long and an extended barrel cylinder 292 cm long at each end of the barrel and separated by a gap for detector services. As of October, 2001, 65% of the barrel modules had been completed at the JINR Laboratory in Dubna, Russia. Extended barrel modules are being constructed in the U.S., where 50% of the modules were completed and in Spain where 73% were completed.

Figure 2. A submodule during stacking

As a practical matter, the steel stacks are assembled first in units called submodules which are then combined into modules (see Fig. 2). A barrel module is made of 19 submodules and an extended barrel module contains 9 submodules. In October, 2001, 90% of the 2405 submodules had been fabricated at sites in Russia, U.S., Spain, and Italy. Extensive measurements are done on each submodule and then on completed modules to ensure that mechanical standards are maintained, especially that the completed module is contained inside its specified envelope and will fit properly with other modules into a barrel structure.

2.2 *Instrumentation with Tiles and Fibers*

After a module is assembled, the plastic scintillator tiles are inserted into the gaps left in the steel structure. Wavelength shifting fibers are held against the edges of the tiles and carry the light to plastic "cookies" which are viewed by photomultiplier tubes inside the girders. All of the roughly 400,000 scintillator tiles have been produced in Russia and inserted into the Tyvek sleeves which protect them and reflect light. 65% of the fibers had been inserted into plastic "profiles" by automatic machinery in Portugal. As of October, 2001, 50% of the modules had been fully instrumented. Fig. 3 shows the fiber routing stage of instrumentation where fibers are sorted and gathered into their plastic cookies.

Figure 3. Fiber routing stage at end of instrumentation work on a module

2.3 *Electronics and Readout*

Photomultiplier tubes and front-end electronics are packaged in drawers which are inserted into the girders at the outer radius of each module. A drawer is shown in Fig. 4. In October, 2001, 45% of the 10010 PMTs and 3% spares had been delivered and tested in six different collaborating institutes.

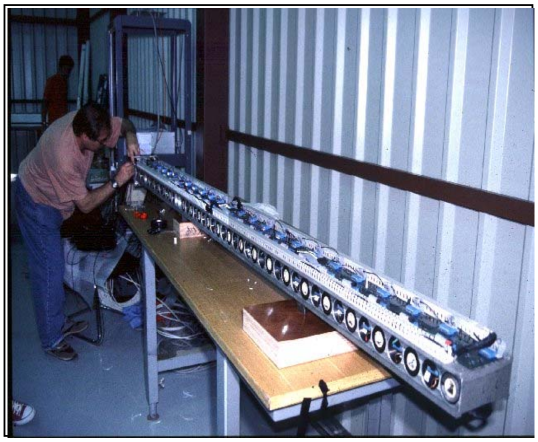

Figure 4. A readout drawer containing photomultipliers and front-end electronics

2.4 *Calibration and Testing*

Each module will be tested and calibrated with a Cs^{137} source which moves through

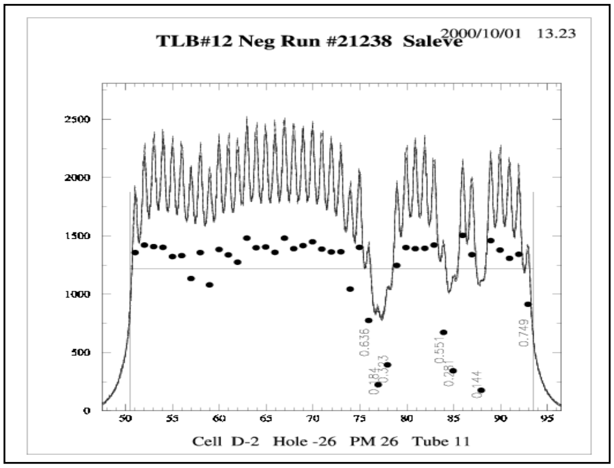

Figure 5. Typical response data from the Cs source

the module and illuminates each scintillator tile. Fig. 5 shows an example of the data obtained on a pass of the source, with a peak as the source passes each scintillator tile.

3 Calorimeter Beam Tests

Extensive measurements have been made with modules in a test beam, using the arrangement shown in Fig. 6. Exposures have been made with muons, pions, and electrons. Fig. 7 shows the response of the calorimeter at 180 GeV.

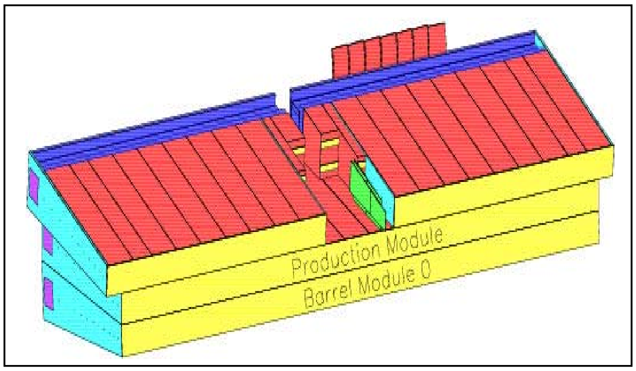

Figure 6. Arrangement of modules for test beam

3.1 Calibration and light yield

The light yield has been estimated from the statistical variation of differences in signal between the fibers and photomultiplier tubes. We find typically 50 to 60 photoelectrons per GeV energy deposited. Gains on the photomultiplier tubes are adjusted to yield 1.2 pC per GeV.

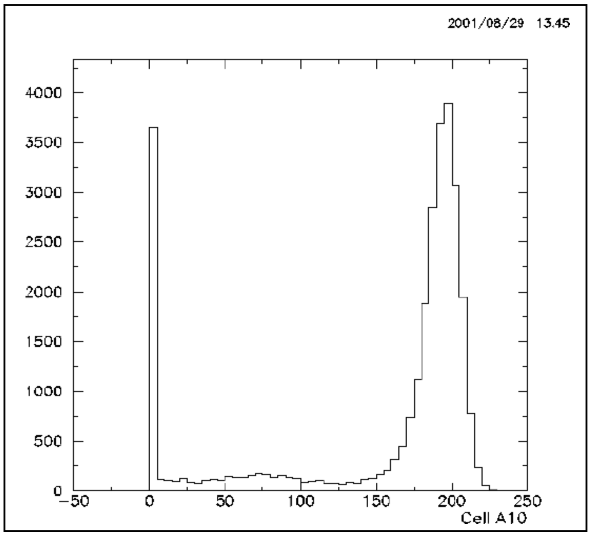

Figure 7. Response to 180 GeV muons, pions, electrons

3.2 *Muon Energy Loss in Iron and Nuclear Form Factor Effects*

Energy losses of muons at very high energies, up to 10 TeV, have been measured in cosmic-ray experiments [3–5]. In these experiments muon energies were measured with a magnetic spectrometer, and reasonable agreement between data and calculations was found, but not in the region of very small energy losses [5]. Energy losses of muons up to 300 GeV were measured in various accelerator experiments [6-10]. A reasonable agreement with theory was reported in [6-8]. Preliminary results of 300 GeV muon energy loss measurements in iron (lead) indicated [9] about 7% (10%) higher probability compared to Monte Carlo predictions.

A measurement was performed in 1998 with 180 GeV positive muons incident on a preseries module of the ATLAS Tile Calorimeter (Module 0). In this setup muons traversed 5.6 m of finely segmented iron and scintillators, thereby providing high statistics and high granularity data. Contamination from hadrons and muon decays in flight are eliminated using the first 1.5 m of the muon track in the calorimeter.

The results are compared with theoretical predictions in Fig. 8. Particular attention is given to muon bremsstrahlung which is the dominant process leading to large energy losses. In this region we clearly observed for the first time the suppression of bremsstrahlung due to the nuclear elastic form factor.

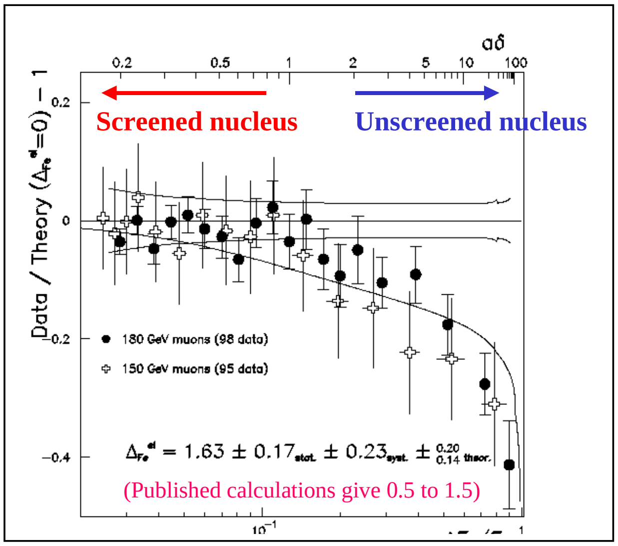

Figure 8. Response to 180 GeV muons, pions, electrons

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