The ATLAS scintillating tiles hadronic calorimeter

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ABSTRACT

The scintillator tile hadron calorimeter, adopted by the ATLAS experiment, uses as absorber, scintillating tiles placed in planes perpendicular to the colliding beams and wavelength shifting fibre readout. The first prototype has been built and tested with pion, electron and muon beams at the CERN S.P.S.

1 Introduction.
The ATLAS collaboration [1] proposed to build a general purpose proton-proton detector for the Large Hadron Collider, capable of exploring the new energy regime which will become accessible. One of the main subsystem of the ATLAS detector is a large scintillating tile hadronic barrel calorimeter.

The technology for this calorimeter is based on a sampling technique using steel absorber material and scintillating plates readout by wavelength shifting (WLS) fibres. New to this approach is the orientation of the scintillator tiles within the absorber [2]. To allow a simple, economical and modular assembly, tiles lie in planes perpendicular to the colliding beams; for better sampling homogeneity, tiles are staggered in the radial direction, corresponding to the shower axis for small $\eta$. This orientation does not affect the energy resolution for hadrons and jets and assures short secondary particle track lengths. Radially oriented WLS fibres collect light from the tiles at both of their open edges and bring it to photomultipliers (PMT's) at the periphery of the calorimeter. Each PMT views a specific group of tiles, through the corresponding bundle of fibres with this readout scheme obtaining a three dimensional segmentation. In the first year of the project RD-34 (1993), a three module prototype calorimeter was constructed and tested in standalone mode (no e.m. section in front) at the CERN SPS. Besides confirming expectations on uniformity and energy resolution, the data showed that excellent signal linearity could be obtained by a simple sampling correction method. These results, now published [3], proved the validity of the idea and led ATLAS to adopt this concept for the barrel hadronic calorimeter (Tile calorimeter, $|\eta| < 1.6$). To extend the project through 1994 and 1995, two additional prototype modules were constructed and instrumented. Also, in 1994 a preliminary beam test with a prototype e.m. LAr accordion calorimeter, in front of the calorimeter prototype was performed.

A rather complete design of the ATLAS barrel calorimeter, based on the experience of almost three years of R & D is now available and construction of the ATLAS calorimeter module prototype has begun. The Tilecal collaboration, RD-34, counts now on 19 institutions with about 200 physicists and engineers, who give it a solid technical and human base and the strenght necessary to accomplish the necessary tasks.

2 Mechanical construction.
The Tile calorimeter consists of a cylindrical structure and is subdivided into a 5.64 m long central barrel and two 2.65 m long, extended barrelss. Each of them is subdivided into 64 independent azimuthal modules (Figure 1). The mechanical structure of the calorimeter consists of a large number of trapezoidal steel plates, which periodically repeat along the $z$ direction. Each period is a stack of four layers. The first and the third layer are formed by large trapezoidal steel plates (masters) 5 mm thick, the second and the fourth layers alternate small trapezoidal steel plates (spacers), 4 mm thick (11 different sizes) and scintillator tiles, 3 mm thickness. The scintillator plates are inserted once the stack is completed and compressed.

3 Scintillator Tiles and Fibres.
The main considerations in the choise of scintillating tiles are photoelectron yield, uniformity of response within

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Figure 1: Principle of the tile hadronic calorimeter

A tile, tile-to-tile fluctuations, cost. The scintillator tiles are produced by injection molding technique [4], which eliminates operations such as machining to size and polishing edges. Optically transparent granulated polystyrene is used as a base material with the additional of two scintillation additives (1.5% of PTP and 0.04 POPOP). The dopants and their concentrations have been chosen to optimize the light yield and the efficiency of the light coupling to the fibre.

The light emitted by the scintillator tiles is transmitted to 1 mm diameter wavelength shifting fibres with a decay time of the order of 10 ns. The fibre ends opposite to the PMT's are aluminized by sputtering, which gives a reflectivity of about 85%. Attenuation length for aluminized fibres are around 4 m. Sample fibres were investigated as a function of cladding type, dopant concentration and UV absorber concentration, mechanical stress, splicing technique and radiation hardness. The double-clad fibres, BCF91A type from Bicron and Y11(200)MS from Kuraray give best results. [5]. Tile/fibre setups have been extensively tested within RD-34 using collimated $\beta$-sources ($^{106}$Ru or $^{90}$Sr) and scanning over the scintillator surface. Measured light uniformity (Figure 2) is typically 5% when adding the left and right readouts with attenuation lengths in the scintillator between 30 cm and 40 cm. The uniformity and the light yield (Figure 3) are improved by using a simple masking technique and a proper tile-fibre coupling geometry [6]. The tile-to-tile response fluctuation and fibre-to-fibre (including fibre coupling) non-uniformity have been measured on the sample of about 4000 injection moulded tiles produced and used in the prototypes. For both cases the achieved response non-uniformity is about 5-6% more than adequate for a hadronic calorimeter.

4 Calibration, intercalibration and monitoring.

For the reason to obtain a well-calibrating energy response from the tile calorimeter, several interrelated issues must be addressed: monitoring of short-time drifts, equalisation of the response of readout cells and a precise energy calibration for the joint e.m. and hadronic barrel calorimeter. Short-term PMT gain drifts will be calibrated by means of a laser-driven light pulsing system. A movable radioactive source system will be used to, first equalise and then monitor the gain of all cells. Absolute energy calibration will be obtained with a beam test. The calibration will be transferred to the entire set of calorimeter modules and maintained in time using a movable radioactive source. Every scintillator tile is traversed by a hollow tube, into which a gamma source ($^{137}$Cs, $E_{\gamma} = 0.662\, MeV$) can be inserted. As the source moves along the tube, it consecutively excites every tile, the resulting current in the corresponding PMT is proportional to its gain and to the overall calorimeter photoelectron yield. In calorimeter prototype tests, for a measured PMT gain of about $10^6$, the 1994 prototype modules give currents of about 250 nA [7]. The digitised voltages are used to calculate online the response of each cell, averaging over all tiles and using about 6 measurements per tile. Equaliza-
tion of the response is simply achieved by adjusting the PMT HV to obtain the same average signals for each cell. These average values are measured again at later times as a check of response stability.

The correlation of the source intercalibration with high energy particle response has been investigated by exposing the calorimeter prototypes to a muon beam perpendicular to the tiles. The muon response has been found to be correlated with the source response to within 6%.

5 Readout Electronics.
The resolution of the readout system must be small compared to the intrinsic energy resolution of the calorimeter. For hadrons that interact only in the tile calorimeter, the resolution has been measured to be $\sigma/E = 47%/\sqrt{E} + 2\%$. The calorimeter readout is mounted in a system of drawers. The PMT subsystem contains a light mixer, the phototube with local electronics and magnetic shielding. The number of channels per drawer reflects the readout segmentation. With two PMT’s per calorimeter cell, a drawer contains between 14 and 24 channels, depending on its location.

Two generation of prototypes and about 12 individual PMT’s have been tested and several of the desired performances have been achieved: quantum efficiency of about 17% at 480 nm, fast and clean pulse shape, fibre-to-fibre response uniformity at the level of few %, linearity as a function of the anode current, from both the optimizations of the dividers and light mixers, insensitivity to the magnetic fields up to 200 Gauss in any directions with individual shielding and insensitivity to fast neutrons.

Measurements of the effect of a magnetic field [8] on the light output of scintillating tiles and on the PMT shielding have been performed. The results show that in the expected magnetic environment the light output will increase by no more than 1% and that individual PMT shielding will not be a problem.

6 Prototypes and performances in beam tests.
Five 1 m long prototypes have been constructed and exposed to the test beams in the framework of RD-34 [9]. Each spans $2\pi/64$ in azimuth, with a $100\times20$ $cm^2$ front face and 180 cm in radial depth, going from an inner radius of 200 cm to an outer radius of 380 cm, corresponding to a total radial depth of about 9 interaction length. Details about the procedure adopted for the construction of the five modules can be found in [10]. The three prototypes in 1993 and the five in 1994, have been exposed to high-energy pion, electron and muon beams at the CERN SPS. Two different setups have been used to test the five prototype modules. In the standalone mode the modules have been positioned on a scanning table allowing high precision movements along any direction. Beam chambers and beam defining elements have been placed just in the front of the scanning table. A large scintillator wall covering about 1 $m^2$ of surface has been placed on the side and on the back of the calorimeter to qualify back and side leakage. For the combined run the Tile calorimeter has been placed on a fixed table, behind the LAr accordion cryostat. Both the Tile calorimeter and the cryostat have been tilted with respect to the beam axis by 11.3° to ensure full containment at least in the electromagnetic part.

Results obtain in 1993 and 1994 show very similar performances for pions and confirm the expectations of good response uniformity, energy resolution and signal linearity. In 1994 tests, the central sector shows the best performance in terms of light yield and light uniformity, due to the use of double-clad fibres and also, of an improved tile geometry.

The energy resolution for pions has been studied in the energy range from 20 to 300 GeV and at angles of incidence in $\theta$, from $0^\circ$ to $45^\circ$. The energy spectra are symmetric at all energies and display small or no tails on the high energy side. The observed energy resolution at 20° is shown in Figure 4(a). For raw data a resolution of $\sigma/E = 47%/\sqrt{E} + 2.2\%$ is obtained. This result has been improved by using a simply depth correction for the four depths [10]. This technique allows to adjust downwards readout cells with large signals, due to electromagnetic clusters [11]. The resolution becomes $\sigma/E = 45%/\sqrt{E} + 1.3\%$, in reasonable agreement with detailed GEANT simulations.

Uniformity has been studied with pions of 40 and 80 GeV at an angle of incidence of $10^\circ$. In Figure 5, a 60 m scan across the front calorimeter face is shown. The response is uniform to within 0.9% r.m.s.. The $e/\pi$ ratio has been determined to lie between 1.1 and 1.2 over the energy range studied. As is well known, $e/\pi \pm 1$ causes deviations from linearity in the hadronic response and
hadron energy resolutions are competitive with those obtained with conventional sampling iron calorimeters even when the calorimeter is exposed to hadrons without an upstream e.m. compartment. The resolutions obtained in such a standalone mode can be further improved with a simple sampling correction procedure, which has the important additional benefit of yielding a very good linearity versus incident hadron energy. Extensive studies [12] conducted within the collaboration, have shown that this calorimeter can tolerate a radiation exposure equivalent to at least 10 years of operation at the LHC design luminosity with negligible radiation damage.

RD-34 has ended its first generic R & D phase and is now ready to enter to a new period, where the Tile calorimeter has to be finalised in its design for the ATLAS configuration and then constructed. A first step in this direction will be made over the next two years, where a complete fullsize module zero for both, the barrel and extended barrel of the ATLAS detector will be constructed and tested, both in standalone mode, as well as in combined mode.

References
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