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Long Term Monitoring of Tilecal Response in ATLAS: Design Considerations

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Abstract

Long term monitoring of the TILECAL response in ATLAS will use the quasi-DC current due to minimum-bias events, as well as the current induced by a movable radioactive source (in machine–off periods). In this note, the general design parameters of the monitoring system are specified, based on the information currently available. Minimum bias energy depositions are calculated, leading to a range of expected currents over the calorimeter. These are compared to expected source currents, under the same general operating conditions. A general design for the current-integrating electronics and readout is presented.

1 Long term monitoring strategy

To obtain useful jet and missing energy measurements the hadron calorimeter needs the response of the readout cells to be equalized and a precise energy calibration to be maintained at all times. To achieve these goals it is necessary to monitor over the duration of ATLAS the response of all calorimeter cells. The systems that will monitor short-term variations, typically due to gain drift of the readout electronics or of the PMT gain, are described elsewhere [1]. Other factors, such as aging or radiation damage of the optical components, may produce variations in response over a much longer time scale, from days to years; they would typically lead to slow changes in the photoelectron yield of the calorimeter. Such effects are best monitored by measuring light produced in the calorimeter by the passage of radiation.

Two complementary methods are envisaged: monitoring the PMT current due to the minimum-bias (MB) interactions at data-taking time, and measuring the current induced by a movable radioactive source, during machine off periods. The overall strategy is as follows:

1. The movable radioactive source will first be used for quality control, after assembly of each module, and for the initial equalization of the response of cells in a module; the system developed for tile calorimeter prototypes and the results obtained are described in another note [2]. On a longer time scale, source current measurements will allow to maintain in time the absolute energy calibration established on a few calorimeter modules using test beams. Measuring the response of all calorimeter modules to the same radioactive source will allow to transport this calibration to the modules that have not been exposed to a test beam and then to maintain it in time.

2. The expected azimuthal symmetry of MB interactions permits to intercalibrate cells at the same η. If the MB current in the hadron calorimeter turns out to be proportional to the beam-beam interaction rate, without appreciable contributions from other beam loss mechanisms, the luminosity–scaled MB currents allow to continue monitoring the calorimeter response in time. The dependence of the MB signal on η must be measured at least once; then the response of the whole tile calorimeter can be followed in time.

From the above considerations it can be seen that MB measurements need to be compared to source current measurements at least a few times, in order to use them for long-term monitoring; on the other hand, their availability at all data-taking times makes them complementary to the source measurements, besides offering a quick diagnostic tool in case of accidents such as beam losses. If both tools turn out to be equally reliable they will provide useful redundancy.

Designing the readout system requires to know at least approximately the amplitude and frequency spectrum of the MB signal. Such estimates, based on MonteCarlo simulations of MB collisions in ATLAS, are given in section 2.

The expected MB and radioactive source signals are found to have rather similar amplitude and frequencies, therefore the same electronics can be used to measure the time-averaged current from either source. The conceptual design of the current readout is given in section 3, together with dynamic range considerations.

Recording the response of the 192 modules that compose the tile calorimeter requires a fairly elaborate source drive system. The requirements on such a system are given in section 4, while three different source drive concepts are schematically described in section 5.

2 Minimum Bias current estimates

The mean energies deposited at each bunch crossing, at different depths and pseudorapities, in the tile calorimeter were estimated by using full Montecarlo simulations of the ATLAS detector. From the energies, currents were estimated based on the measured tile calorimeter photoelectron yield and the assumed PMT gain.

2.1 Energy depositions

Consistent with ATLAS Technical proposal guidelines, a design luminosity of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and an inelastic cross section of 70 mb were assumed, giving 17.5 MB events/crossing at the LHC bunch crossing frequency f = 40MHz. Three MB event tapes (i06318, i06320, i06321) for a total of 1227 events were used; these events were generated by PYTHIA 5.7, with the standard ATLAS tuning. The interactions with the current ATLAS setup were simulated with the DICE package. The mean energies per bunch crossing deposited in $\Delta\phi \times \Delta\eta = 0.1 \times 0.1$ cells, for the three radial layers, are pictured in Fig. 1; the barrel and external barrel parts are separately shown. As expected, there is a factor of about 3 less energy in the second than in the first (most internal) layer, and a further reduction factor of 10 in the most external layer.

Fluctuations in energy depositions must also be simulated in order to properly specify the readout electronics; for this purpose, the *rms* value of the energies/crossing was also calculated, by bunching together in each simulated crossing a number of MB collisions randomly extracted from a Poisson distribution with mean μ = 17.5. The *rms* energy depositions per cell (as well as the means, in more readable form) are given in the plots of Fig. 2 (central barrel) and Fig.

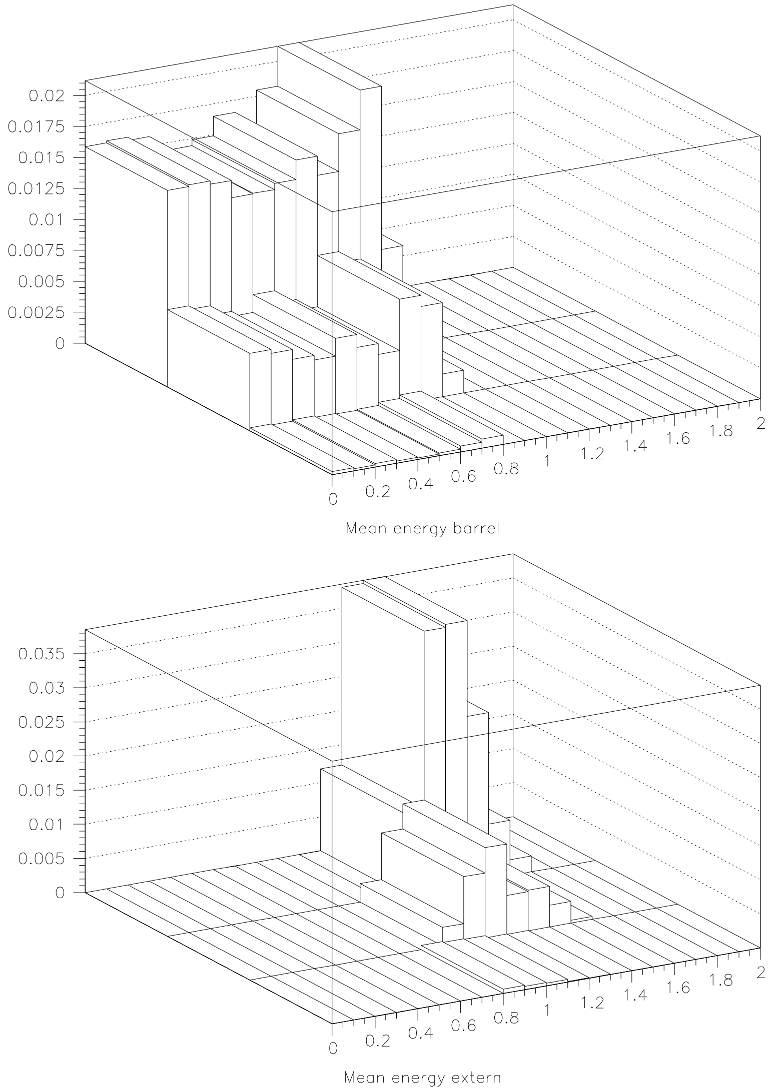

Figure 1: Mean Energy distribution

3 (external barrel). The *rms* values are typically a few times larger than the means, implying that even at these interaction rates the occupancy of calorimeter cells is small. Two typical MB energy spectra are shown in Fig. 4; events with less than 25 MeV/cell deposits (corresponding to less than 1 photoelectron/cell) give negligible contribution to the mean deposited energy.

It should be kept in mind that MB energy estimates have an uncertainty of ±50%, due to uncertainties in the extrapolation to the LHC energies.

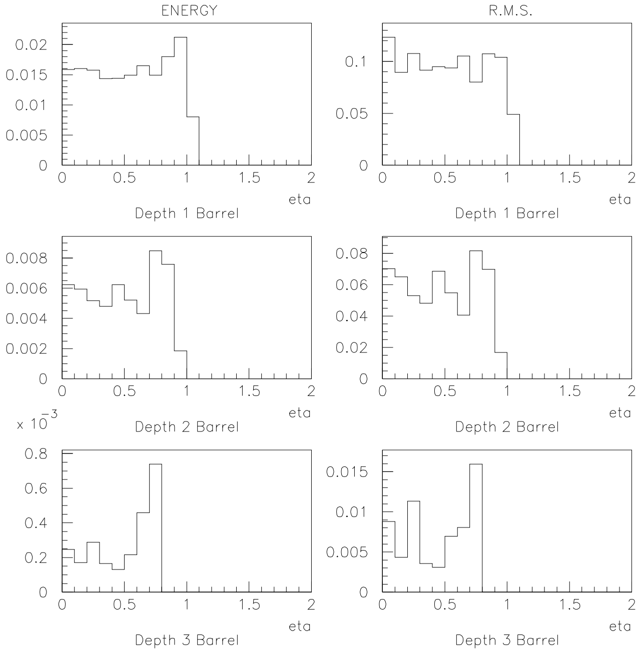

Figure 2: Mean and r.m.s energy depositions for Barrel cells, vs. pseudorapidity

2.2 Minimum bias currents

The conversion from deposited energy E to the mean PMT current I is obtained by

$$I = \frac{f n_{PE} G e}{2} E$$

where $f = 40$ MHz is the crossing frequency, $n_{PE} = 40$ is the number of photoelectrons/GeV detected in the tile calorimeter [3], $G = 10^5$ is a PMT gain compatible with Technical Proposal specifications [4], and e is the electron charge. The factor of 2 in the denominator is introduced because each cell, receiving an energy E, is read out by two photomultipliers. The energy/current conversion factor is 12.8 nA/MeV.

Table 1 summarizes the maximum and minimum estimated energies and currents per cell in the three calorimeter layers. The numbers are extracted from Figs. 2 and 3, suppressing the obvious statistical fluctuations, and are given as a basis for the design of the MB current readout electronics (in this table, the signals in layer 3 are summed over cells of $\Delta\phi \times \Delta\eta = 0.1 \times 0.2$, to reflect the coarser segmentation of the third TILECAL layer).

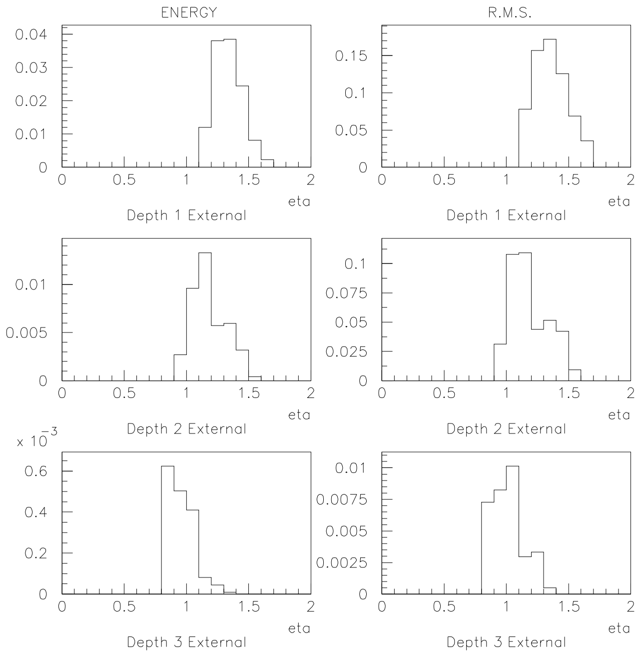

Figure 3: Mean and r.m.s energy depositions for External Barrel cells, vs. pseudorapidity

	Maximum		Minimum	
Layer	E (MeV)	I (nA)	E (MeV)	I (nA)
1	36	460	8	102
2	11	141	2	26
3	1.2	16	.4	5

Table 1: Maximum and minimum energy depositions in each layer and its corresponding current.

3 Current readout

The results of the previous section show that the innermost calorimeter layer has an occupancy of 5 to 10%, corresponding to a frequency of 2 to 4 MHz. Outer layers have signals of smaller frequency, roughly in proportion to the average energy depositions.

It is useful to compare this signal to that obtained in the Tilecal prototype with a movable radioactive source. In the 1994 tests [2], with a PMT gain of 10^6,

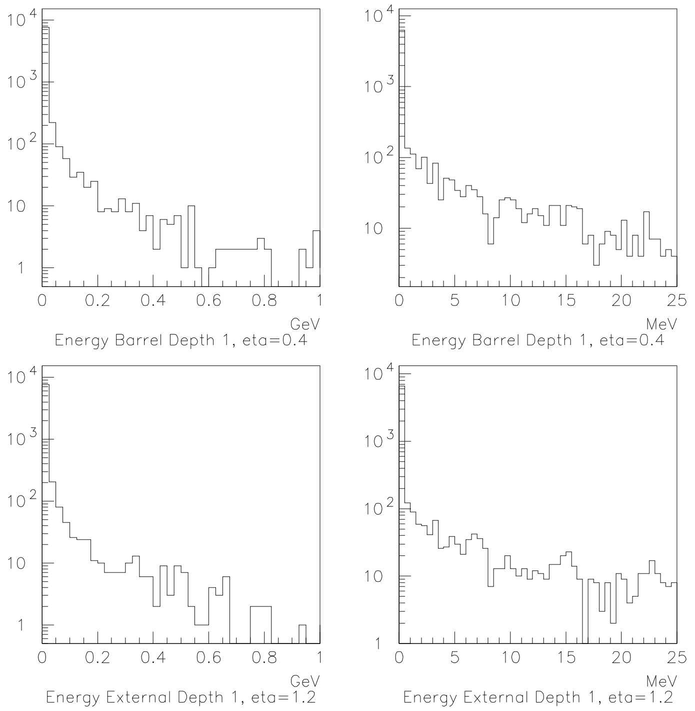

Figure 4: Deposited energy spectrum for two typical cells of the Barrel and the Extended Barrel

a 5 mCi Cs^{137} source ($E_{gamma} = 0.66$ MeV) typically produced currents of 300 nA; this corresponds to a single photoelectron rate of about 2 MHz. A similar source, if used in the ATLAS movable source calibration system, will give a 30 nA signal (because the PMT gain is envisaged to be 10× smaller); this current is in the middle of the range expected for MB currents at the design luminosity, as shown in Table 1. The average value of such small signals is simply obtained by integrating the signals with a suitable RC network, placed across an operational amplifier to provide impedance match to the following stages. This concept was successfully tested in 1994 tests [2]; the system is very similar in concept to the scheme illustrated in Fig. 5.

In this scheme, each PMT output is viewed by an operational-amplifier integrator and the pulse–shaping network used as the first stage of the front–end electronics for physics readout. A JFET-input operational amplifier is most suitable to deal with these relatively small currents. The output is a DC voltage (on time scales ¡¡ than the RC time constant) which is digitized by a successive-approximation 12-bit voltage ADC. It is convenient, to minimize costs, to multiplex the DC signals from several PMTs; a drawer, containing on the average 20

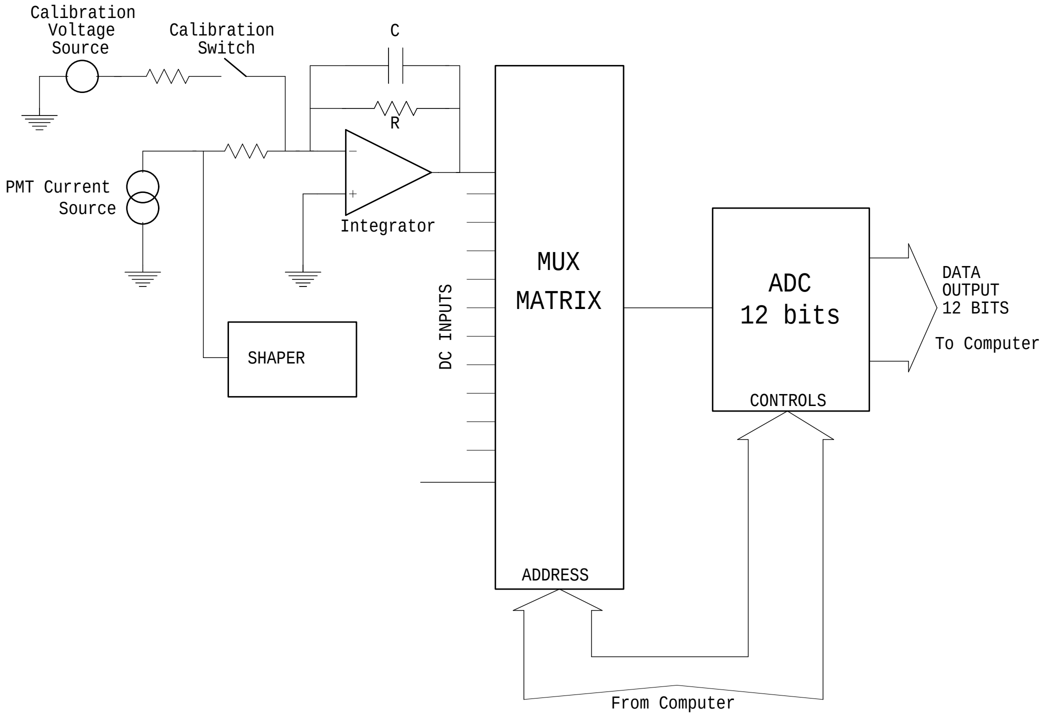

Figure 5: Current integration electronics scheme

PMTs, is a logical system unit over which to multiplex. Also shown in Fig. 5 is the integrator circuit calibration scheme, which is based on injecting a precisely known and stable DC current in turn into all integrators.

While the value of the feedback resistor R is chosen to match the PMT current range to the ADC voltage conversion range, the value of the RC time constant must be such as to limit the statistical fluctuations of the DC signal within a small fraction of its mean value. For the source calibration circuit developed in 1994, a time constant of 20 msec (4×10^4 pulses/time constant) was found to be sufficient to limit the fluctuations due to the stochastic nature of source emission below 1%. The minimum bias current fluctuations are larger, because of the tails of the cell energy spectra (see Fig.4); we estimate that a time constant of 100 msec will be needed.

The maximum MB currents shown in Table 1 span a range of 25; considering furthermore that these currents will be much lower in the early LHC operation period, it is clear that a dynamic range of 12 bits would not be sufficient to accomodate the MB current variation in the whole calorimeter (all layers and all η range) as the luminosity rises towards the design value, if an electronic precision of about 1% (5 to 6 bits) is to be maintained. The logical design choice is to plan different current to voltage conversion factors for the current readout circuits corresponding to the three calorimeter layers; this reduces the required dynamic range to the variation of MB currents over η (a factor of 3 to 4, as shown in Table 1) times the variation in luminosity. It can be easily seen that choosing the maximum digitization to correspond to design luminosity, the 12 bit ADC allows to reach a precision of about 1% down to luminosities of about $10^{33}/\mathrm{cm}^2\mathrm{s}$ over the entire range of η. To allow for uncertainties in MB current estimates, one might more conservatively design for filling only 1/2 of the ADC range at design luminosity; the resulting digitization error would still be acceptable.

Hard-wiring different gains for different calorimeter layers implies that the movable radioactive source intensities must scale correspondingly, *i.e.* less intense sources must be used for the outer layers.

References

[1] Z. Ajaltouni *et al.*, ATLAS Internal Note TILECAL–NO–39.

[2] G. Blanchot *et al.*, ATLAS Internal Note TILECAL–NO–44.

[3] ATLAS Technical Proposal, Calorimetry section 5.3.3

[4] ATLAS Technical Proposal, Calorimetry section 5.5