Digital Signal Reconstruction in the ATLAS Hadronic Tile Calorimeter

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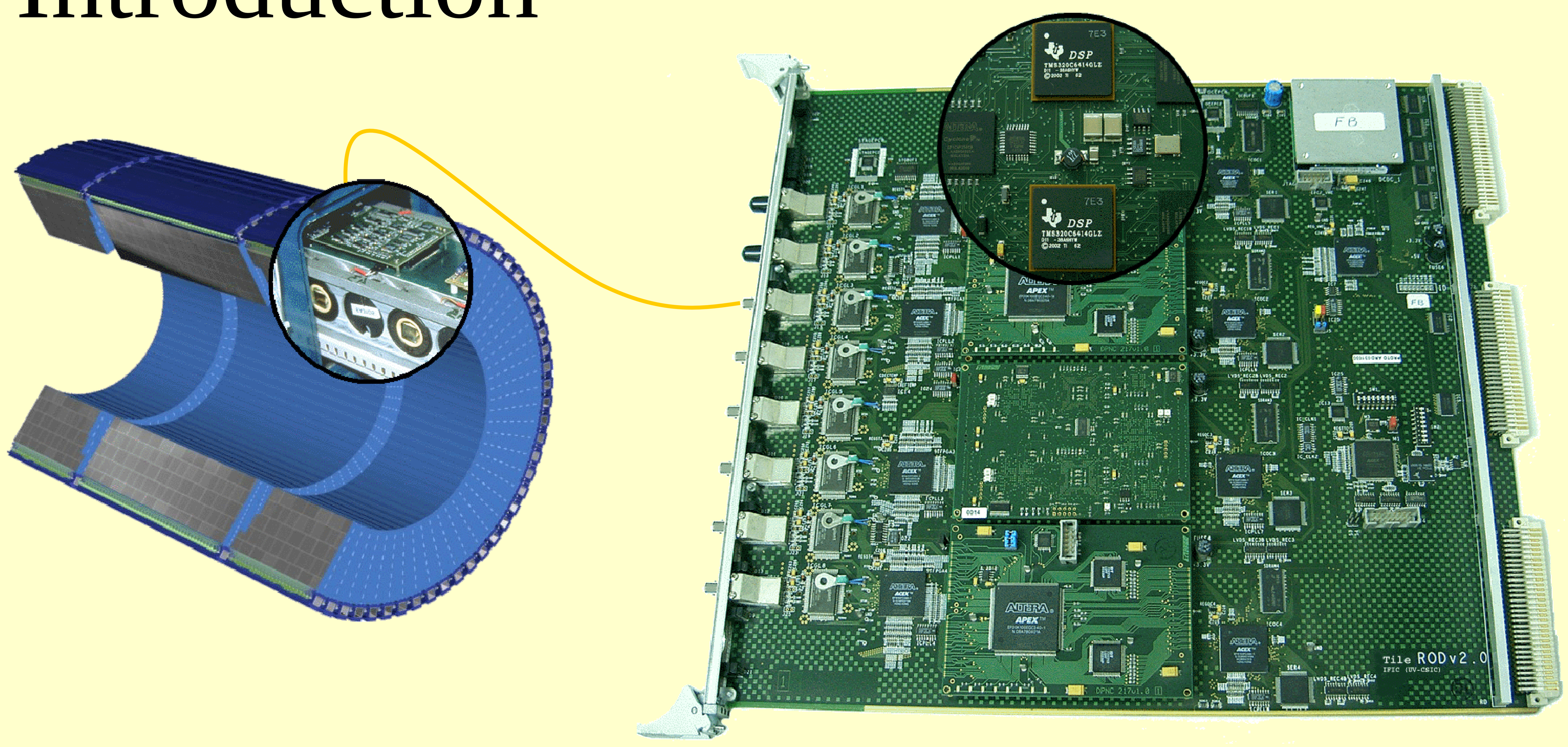
Introduction



ATLAS is a general purpose experiment designed to detect signals of new physics in the large hadron collider (LHC) being constructed at CERN[1]. The Tile Calorimeter (TileCal) is the central hadronic calorimeter of the ATLAS detector. It is made of iron and plastic scintillators whose light is driven to photomultipliers through optical fibers. Signals from the photomultipliers are shaped and digitalized every 25ns by a 10 bits ADC.

The Read Out Driver (ROD) is an electronic card which receives the digital samples from the TileCal front-end electronics, analyzes them and sends the output to the second level trigger of the detector[2]. Each ROD contains up to four processing units (PUs) equipped with the last generation of digital signal processors (DSPs). The PUs implement an algorithm to reconstruct the amplitude of the photomultiplier signal from its digital samples. This amplitude is proportional to the energy deposited in the active medium of the calorimeter and therefore a proper amplitude reconstruction means a good energy reconstruction.

The Algorithm

The Optimal Filtering (OF) algorithm reconstructs the amplitude, time and pedestal of an analogical signal through weighted sums of its digital samples. This algorithm is though to be processed online in the DSPs and therefore it should be a compromise between simplicity – to fulfill the limited processing time available (10 µs) – and reliability to reconstruct properly the parameters of the signal event by event. It was developed to solve the integration time compromise in the signal of liquid ionization calorimeters[3]. The equations which summarize the algorithm are:

$$A = \sum_{i=1}^{n} a_i S_i \ , \quad \tau A = \sum_{i=1}^{n} b_i S_i \ , \quad p = \sum_{i=1}^{n} c_i S_i \ .$$

where A is the amplitude, τ the timing of the signal, p the pedestal, n the number of samples, a_i the weights for the amplitude, b_i the weights for the time, c_i the weights for the pedestal and S_i the digital samples.

Weights Calculation

The optimal filtering weights are calculated taking into account two factors: the noise autocorrelation function and the shape form of the signal at the input of the digitizer. The weights minimize the sigma of the amplitude, time and pedestal distributions while fulfilling the reconstruction requirements. With these two conditions and using the Lagrange multipliers method we obtain a system of n+3 equations and n+3 unknowns. Its solution is a vector which contains the optimal filtering weights:

$$\begin{pmatrix} R_{11} & R_{12} & R_{13} & g_1 & g'_1 & 1 \\ R_{21} & R_{22} & R_{23} & g_2 & g'_2 & 1 \\ R_{31} & R_{32} & R_{33} & g_3 & g'_3 & 1 \\ g_1 & g_2 & g_3 & 0 & 0 & 0 \\ g'_1 & g'_2 & g'_3 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 \end{pmatrix} \bullet \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ \xi \\ \psi \\ \zeta \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{pmatrix}$$

The equation is an example for $n = 3$. The terms R_{ij} correspond to the noise autocorrelation matrix. The terms g_i and g'_i are the shape form factors and their derivatives respectively.

The noise autocorrelation matrix is set to the unitary matrix in this study due to the low noise correlation found in the TileCal electronics.

The shape form is reconstructed using a charge injection system which is part of the calibration system of the TileCal front-end electronics. The shape form reconstructed is fitted to an analytical function. The terms g_i and g'_i are values of this function (normalized to one in amplitude) and its derivative respectively. They must be calculated at the same position - within the shape form - of the sampling.

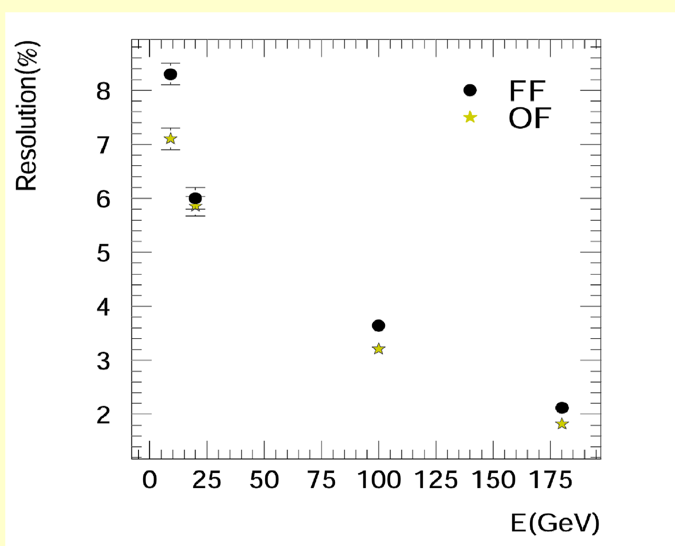
Results

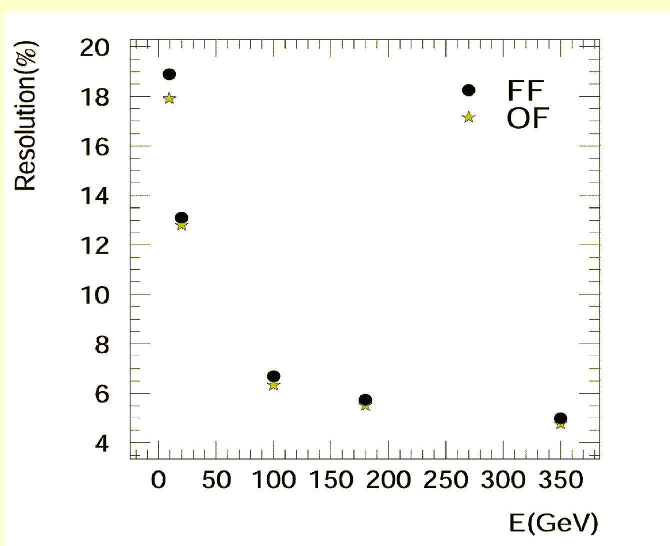
Some of the modules of the TileCal detector have been calibrated under the SPS beam at the H8 CERN facility. A movable table allowed the beam to impinge the detector at different angles. The performance of the OF algorithm has been studied under electrons and pions[4]. In the analysis several cuts were defined in order to eliminate contamination in the beam of undesired particles. The results of the OF algorithm are compared with the Flat Filtering algorithm (FF) which is based on the plain sum of the samples.

For each beam energy the distribution of the energy deposited in the detector fits a Gaussian distribution. The sigma over the mean of the fit defines the resolution of the detector for each beam energy.

The results are promising specially at low energies (more specifically when the number of counts in the ADC is closed to the pedestal) where the impact of the noise in the resolution is more important.

The improvement in the resolution and its simplicity makes OF a good candidate for the online energy reconstruction in TileCal at ROD level.





The figures show the resolution of the detector versus the energy of the beam. The black circles are the flat filtering values values and the green stars the optimal filtering ones. The figure on the right plots the resolution of the detector under pions and the figure on the left plots the resolution under electrons. Both figures show the improvement in the resolution of the OF algorithm. This is more remarkable at low energies when the contribution of the electronic noise is important.

References

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