The ATLAS Liquid Argon Calorimeter Alignment in Time for exotic search

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Résumé

Le calorimétre Argon Liquide (LAr) de l'expérience ATLAS doit pourvoir à la reconstruction d'énergie des les particules qui sont produites au collisionneur LHC. L'alignement au temps des toutes les cellules du calorimétre est essentiel pour garantire une bonne résolution au temps, ce paramètre joue un rôle importante dans beaucoup des théories au delà de Modelé Standard qui prédisent l'existence des particules produite avec un temps de vie mesurable dans le détecteur. Dans ce rapport on se propose de décrire l'alignement en temps des le cellules du LAr que a été fait avec le donnes des collisions proton proton dans l'année 2010.

1.1 Introduction

The Liquid Argon Calorimeter (LAr) system is an important part of the ATLAS detector [1]. It allows to trigger, to identify and to measure electrons, photons and jets of energies ranging from a few GeV to a few TeV. To insure optimal energy reconstruction all the calorimeter readout channels should be well aligned in time. Previous studies resulted in the alignment up to a few ns [2] [3]. Test-beam studies have shown that it is possible to achieve time alignment on the level of 100 ps [4].

A more refined time measurement of the calorimeter signal could have several applications in the ATLAS environment.

It can help in the identification of long lived particles and in the measurement of their decay time. One typical example occurs in the Gauge Mediated Supersymmetric Models in which the neutralino travels a significant distance before decaying into an invisible gravitino and a non-pointing and out-of-time photon [5]. This feature can be used to measure the neutralino lifetime using timing information from the electromagnetic calorimeter of the reconstructed photon direction. A delayed cluster time is expected because of the negative value of $\beta = \frac{v}{c} < 1$ of the massive neutralinos and the longer trajectory through the detector.

Timing information could also be used in searches for exotic particles with anomalously high ionization energy losses to distinguish them from Standard Model backgrounds [6].

Finally at high luminosity the time information may also be used to reject events with large pile-up activity from previous bunch crossings.

This note describes the LAr channel timing alignment as it was performed during the 2010 proton-proton data-taking of the LHC.

1.2 The ATLAS Liquid Argon calorimeter and its signal read-out system

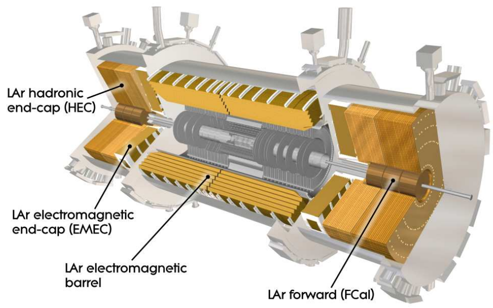

FIGURE 1.1 – Cut-away view of the ATLAS Liquid Argon calorimeter

As shown in Fig. 1.1, The ATLAS LAr calorimeter consists of four subdetectors : the electromagnetic barrel (EM Barrel), the electromagnetic endcap (EMEC), the hadronic endcap and the forward calorimeter.

The subdetectors cover an η-range of up to $|\eta| = 4.9$ where η is the pseudo-rapidity defined like $\eta = -\ln(\tan(\frac{\theta}{2}))$. In addition to the subdivision along η for the EM Barrel and along ϕ for the EMEC, they are separated into three different longitudinal sections or layers (Fig. 1.2). The front layer is finely segmented into strips along η and ϕ, respectively. The middle and back layers are coarser in η but finer in ϕ for the EM Barrel and vice versa for the EMEC. Furthermore in the central region ($|\eta| < 1.8$) the electromagnetic calorimeters are complemented by presamplers (PS).

The LAr calorimeter is a sampling calorimeter made of liquid argon as the active material and lead, copper or tungsten as the passive absorber. When charged particles cross the liquid argon gap between electrodes and absorbers, they ionize it. Under the influence of the electric field, the ionization electrons drift towards the electrode inducing a current.

At the channel level, the treatment of the analog

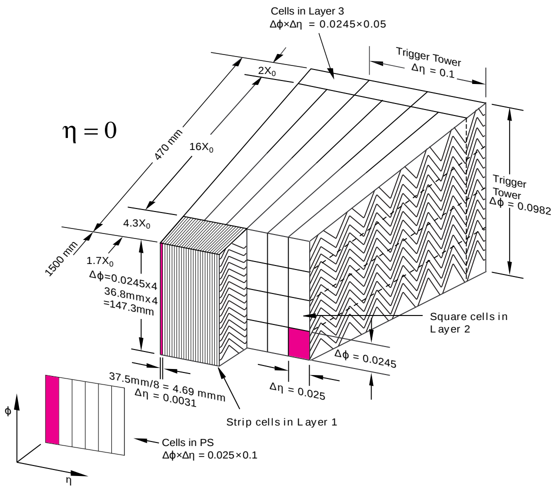

FIGURE 1.2 – The accordion and sampling structure of the EM Barrel calorimeter showing the difference in granularity between the different samplings. Its longitudinal segmentation allows us to look at the shower development [1]

signal is performed in the front-end electronics. On the front-end boards (FEB) located in the Front-End Crates outside the cryostat the signal is first amplified by a preamplifier. In order to accommodate the large dynamic range of pulse (from tens of MeV to a few TeV) and minimize the total noise from the electronics, the signal is shaped and split into three linear scales with a typical multiplicative factors of 1, 9.2 and 92 called low, medium and high gain.

For a given channel these three signals are stored in an analog pipeline [7] until the trigger decision. When the decision is made the signals either from each gain or from the most suited one according to a selection based on the amplitude of the signal with the medium gain, are digitized by a 12 bit Analog-to-Digital Converter (ADC) in five samples spaced by 25 ns.

To each Front-End Crate is associated a crate which contains the read-out driver. The reconstruction of the time and energy of the physics signal for each channel, performed in the read-out driver by the Online Diglital Signal Processor, is based on an Optimal Filtering (OF) algorithm [8].

1.2.1 The Optimal Filtering Method

The Optimal Filtering method provides optimal values of time and energy for each given channel in each given event. This method requires that the exact shape of the expected physics signal after the electronic read-out chain is known. To obtain this shape from the original ionization pulse a transfer function is needed for every channel. This function is obtained from a dedicated calibration runs in which both the input and output pulse are well-known.

The Optimal Filtering Coefficients (OFCs) a_i and b_i are computed per channel from the predicted physics pulse-shape in time using the following formulas :

$$A = \sum_{i=1}^{5} a_i s_i \tag{1.1}$$

$$A\tau = \sum_{i=1}^{5} b_i s_i \tag{1.2}$$

where A is the physics pulse amplitude in ADC counts, τ is the peak-time shift between the reference pulse and the physics pulse and s_i are the ADC samples. These equations are only valid if the values of τ are small. For perfectly timed detector and in-time particles τ must be close to zero, while the larger values indicate the need for better timing or the presence of out-of-time particles in the event. If ADC samples are dominated by noise, Eq. 1.2 does not give reliable results. Than τ is computed only for pulses which have at least one ADC sample larger than four times the noise RMS in that readout channel.

As τ might not be small for some channels, especially in the begining of data taking, there are 8 sets of the OFCs with 3 ns phase-shift between then used in the physics running and 24 sets with 1 ns phase-shift used in the calibration runs to construct the reference physics pulse-shape [1]. Figure 1.3 shows the difference between a predicted signal shape and a real ionization signal in the second layer of the EM Barrel, given by a cosmic muon.

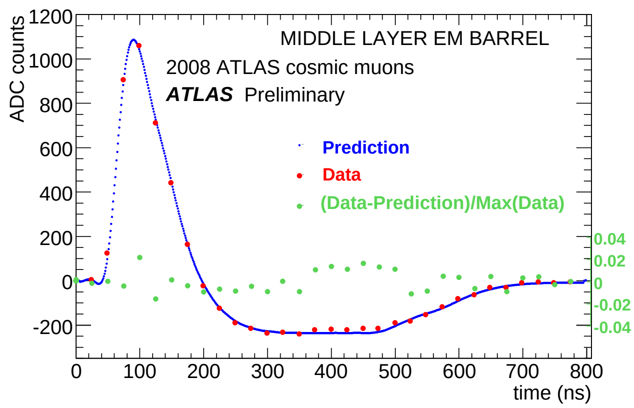

FIGURE 1.3 – A typical pulse for the different EM Barrel middle layers. The blue dots correspond to the prediction, the red ones to the data and the green points correspond to the difference in percentage between data and prediction.

With the present settings (8 phases with 3 ns shift) the sets are chosen in a way that the fourth set of the OFCs corresponds on average to the signal peak being in the third sample.

At the beginning of the LHC data taking, the OFC sets loaded in the LAr Online Diglital Signal Processor are chosen according to the timing information extracted from the calibration data and the complete

1. The predicted pulse is defined with a time difference of $\frac{25ns}{24}$ ns between two consecutive samples and is binned in 24 delay steps spaced by ~ 1.04 ns

knowledge of the readout path [2]. When the physics pulse is recorded A and τ can be calculated from the Eqs. (1.1) and (1.2). If τ obtained is large, the OF procedure is performed iteratively using sets of the OFCs with appropriate phases until the values of τ obtained are less than 502 ps.

Note that a time misalignment of ~ 5 ns between the physics pulse and the reference pulse induces a bias on the reconstructed energy of 0.5% [9].

1.3 Timing analysis

To choose good physics pulses for the timing alignment we use selection as outlined below.

Only channels in the high gain and in which are properly calibrated and for which the OFCs iteration converges are used in the following analysis. A χ^2-like quality factor Q, estimated by comparing the measured pulse shape with the reference shape can be used to select only good pulses.

To calculate only LAr channels that measure an energy above 1 GeV are selected for this study. A measurement above this threshold is extremely unlikely to be the result of electronic noise alone. Figure 1.4 shows this cut in the time vs energy distribution for the four different layers in the EM Barrel. This cut is necessary because for a given channel in a collision event the time spread with to respect to the energy measured is a convolution of the not alignment in time of the channels and the intrinsic time spread of the channel due to the energy dependence of the time resolution ($\sigma_\tau = \frac{a}{E} \otimes c$). With this energy cut for each layer the time spread within a FEB is less than ~ 3 ns.

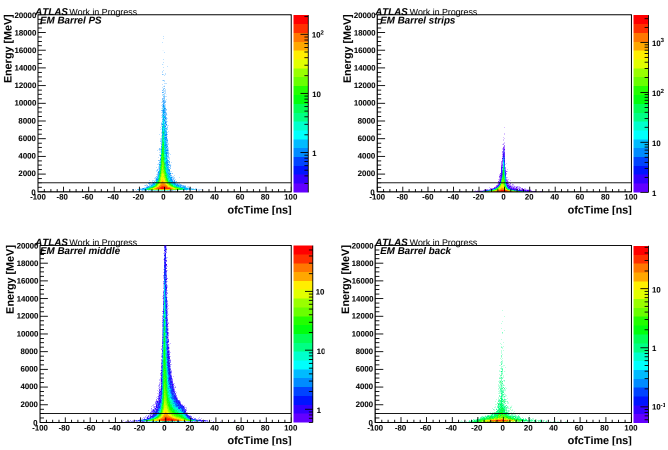

FIGURE 1.4 – The distribution of time vs energy for the four different layers in the EM Barrel.

Any distortion of the signal shape can also produce a bias of the time reconstruction, for that reason another important effect which could compromise the time alignment of the LAr channels is the electric cross-talk. The electronic cross-talk is a phenomena in which a channel share part of their collected current with the neighboring cells. This signal loss in the neighboring cells cause a distortion in the pulse shape.

To avoid that this effect could bias the time measurement we considered for each event the highest energetic channel in each layer (E_1), and we did not take into account the first two neighboring cells (E_2). To increase the statistics we considered also the the highest energy cell after the second neighbors if its energy $E_3 > E_1$.

To align in time the $\approx$ 180k cells of the LAr calorimeter two adjustments are used :

– a global hardware alignment at the level of the FEB time offset
– a channel by channel adjustment of the set of Optimal Filtering Coefficients (OFC).

The latter has a finite minimal correction of $\sim$ 500 ps because there is currently no extrapolation between two concurrent points in the reference pulse which are 1.04 ns apart.

1.4 Timing alignement results

By the end of April 2010 we collected ~ 0.3 nb^{-1} of collision data which gave enough statistics to have at least two events in 94, 4% of the channels. With that data we calculated the FEB time offset as the average of the mean time of each channel for a single FEB for each LAr subdetector. This correction was applied to align the calorimeter time at the hardware level.

At the end of July 2010 with a integrated luminosity of ~ 1.1 nb^{-1} we implemented a channel by channel adjustment having 97, 3% of channels on. For the channel by channel correction we take the single channel average time and we subtract the global run time, this avoids a dependency of this correction on the shift caused by the LHC clock drift found in May 2010 data.

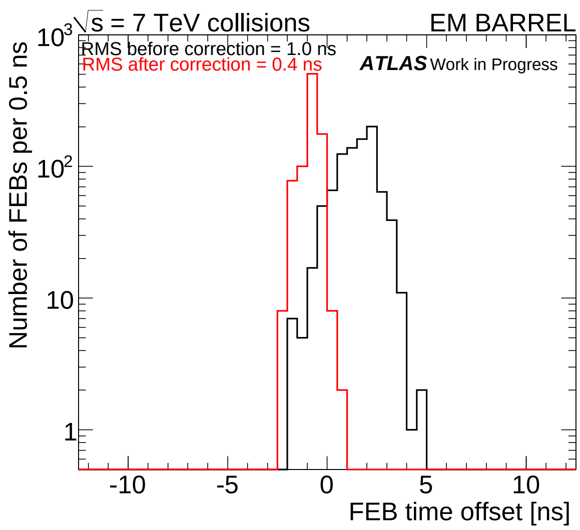

FIGURE 1.5 – For EM Barrel : the black histogram shows the FEB time offsets before the correction, and the red histogram shows the same distribution after the correction were applied.

We applied the single channel correction as a shift to the reference pulse shape. Because the OFC sets come in units of 1.04 ns, time correction precision is driven by this binning constraint.

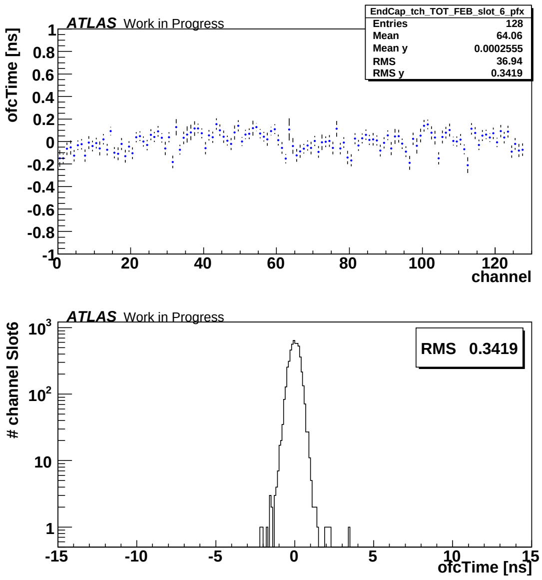

FIGURE 1.6 – For EM Endcap : in the upper plot on average the time versus the channel number in all the FEB in the middle layer with a ϕ simmetry in the actual time situation ; in the bottom plot the channel time spread within a FEB in the middle layer, in the actual time situation.

The effect of the timing adjustment at the level of the FEBs is shown in Figure 1.5. For example, for the EM Barrel of the LAr the black histogram shows the FEB time offsets before the correction, and the red histogram shows the same distribution after the implementation of both the corrections (FEBs time offset and the channel by channel one) with October-November 2010 data corresponding to a luminosity of ~ 8 pb^{-1}. We get a significant improvement because all the FEBs are well aligned with a good RMS of 0.4 ns.

Figure 1.6 shows the distribution of the channels time spread versus the channel number. From the results shown here it is clear that we reach a time spread of the single channels inside a FEB an the order of ~ 400 ns for almost all the channels.

1.5 Outlook

In this paper we have shown the results of our work on the time alignment of the channels of the LAr calorimeter up to a few hundred ps level. Timing measurement becomes more precise with higher statistics acquired. It is not possible to combine runs from the whole year 2010 for this measurement because the LHC clock drift of 2 ns per month introduces a non-negligible shift in our time scale. Thus we have used only the highest statistic runs available. In 2011 the data will be acquired more efficiently thus this problem is removed. We will implement a new round of FEBs corrections based on the final runs from 2010 and then will propose a new set of channel by channel corrections with the early 2011 data. Then we will concentrate on studying small systematic effects, such as a shift in the beam-spot position, the analog pipeline storing delays and the implementation of extrapolation procedure in the OF phase code which would allow the modification of the precision of the channel by channel correction implementation. Those modification wouldn't allow us to reach ultimate timing alignment on the level of 100 ps.

Acknowledgements

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